Stage 1: Environmental Conditions and Problem Definition

JACKFISH BAY

RAP

NORTH SHORE
OF LAKE SUPERIOR
REMEDIAL ACTION PLANS

JACKFISH BAY

RAP

PUBLIC ADVISORY COMMITTEE
COMITÉ CONSULTATIF PUBLIC

September 12, 1991

To Whom It May Concern:

After two years of studying the present and past conditions of Jackfish Bay and the associated Moberly Bay and Blackbird Creek system, we as a Public Advisory Committee (PAC) feel that we have fully outlined our assessment of the conditions in Jackfish Bay and informed the lead agencies in the RAP program of our concerns.

We feel that the Jackfish Bay Stage One document addresses the impaired uses as summarized in our Water Use Goals and that it is a summation of the accumulated details of the conditions existing in the Jackfish Bay Area Of Concern.

The Jackfish Bay Stage One document gives the PAC a sense of accomplishment and encourages us to continue towards the completion and implementation of Stage Two.

Yours sincerely,

Jon Ferguson

Jon Ferguson
Chair
Jackfish Bay
Public Advisory Committee

Remedial Action Plan
Plan d'Assainissement

Canada Ontario

Jackfish Bay Area of Concern

Environmental Conditions and Problem Definition

Remedial Action Plan
Stage 1

Jackfish Bay RAP Team

September 1991

Ontario Ministry of the Environment, Environment Canada, Ontario Ministry of Natural Resources Department of Fisheries and Oceans

North Shore of Lake Superior Remedial Action Plans, 435 James Street S., Box 5000, Thunder Bay, Ontario, P7C 5G6

Remedial Action Plan
Plan d'Assainissement

Canada Ontario

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FORWARD

This document provides a summary of the environmental conditions in the Jackfish Bay Area of Concern in Lake Superior, Ontario, Canada, and identifies specific environmental problems. The report contains a technical summary for use in the public consultation process which was initiated in 1988. This report represents the Stage 1 submission of the Jackfish Bay Remedial Action Plan, in accordance with the Canada-U.S. Great Lakes Water Quality Agreement and the Canada-Ontario Agreement respecting Great Lakes Water Quality.

Several impairments to beneficial uses are identified and described in Tables E and 5.1 of this document based on water, sediment and biota surveys which were carried-out primarily between 1969 and 1988. In October of 1989, the Kimberly-Clark Canada Inc. pulp mill, which is the only point source discharger to the Jackfish Bay Area of Concern, added a secondary effluent treatment system. This resulted in significant reductions in BOD_5, phenolics, and resin and fatty acids. Although some ambient water and biota data as well as effluent data for the period following start-up of secondary treatment are discussed in this Stage 1 document, potential improvements in the ambient environmental quality since 1988 have not been fully assessed.

In order to further assess and update Jackfish Bay environmental quality, the following activities are scheduled for 1990/91:

- an assessment of rehabilitation options for the Blackbird Creek system;
- fish contaminant survey in Jackfish Bay;
- fish reproduction and mixed-function oxidase activity study;
- sediment sampling and analysis; and
- water quality study.

The results of these investigations will be reported in an update to Stage 1, which will be included upon submission of the Stage 2 document.

It is expected that by April 1992 a description of remedial options for Jackfish Bay will be complete. Selection of preferred options will have been completed by July 1992, after extensive review by the public through openhouses, mailouts, etc. A draft Stage Two document should be available by September 1992.

ACKNOWLEDGEMENTS

The Stage 1 Report for the Jackfish Bay Remedial Action Plan was prepared by the Jackfish Bay RAP Writing Team:

Jim Murphy	Environment Ontario, Co-ordinator, Jackfish Bay RAP
John Kelso	Department of Fisheries and Oceans
Ken Flood	Environment Ontario
Ken Cullis	Ontario Ministry of Natural Resources
Linda Melnyk-Ferguson	Ontario Ministry of Natural Resources
Keith Sherman	Environment Ontario, Water Resources Branch
Ian Smith	Environment Ontario, Water Resources Branch

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Cindy Jardine	Environment Ontario, Water Resources Branch
Nellie de Geus	Environment Canada
Laurie Sarazin	Environment Canada
Helmut Pfeiffer	RAP Biologist
Ljubica Pelletier	RAP Facilitator
Mary Sean Burgham	RAP Assistant
Ruth Berzel	RAP Technical Writer
Ray Boivin	RAP Technical Assistant
Jim Schmidt	Wastewater Technology Centre
Daryl Cowell	Geomatics International Inc.

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Chris Joubert	Past Chair, Township of Terrace Bay
Bob Baxter	Kimberly-Clark Canada Inc.
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Jon Ferguson	Chair Public
Gerald Landriault	Ducks Unlimited
Ryan LeBlanc	Save Ontario's Shipwrecks
Jim Bryson	Charter Boat Services
Dave Daniels	U.P.I.U. Local 665
Bob Langford	Public
Jack Moore	Public
Rod Mercure	Public
Ron Martel	Minnova Mines
Lance Stewart	Public

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EXECUTIVE SUMMARY

1 INTRODUCTION

Jackfish Bay was identified in 1985 by the International Joint Commission (IJC) as one of 42 Areas of Concern (AOC) in the Great Lakes Basin. There are currently 43 AOC. Areas of Concern were identified based on known impairments of beneficial uses. Jackfish Bay was originally listed as an AOC based on problems related to conventional pollutants, heavy metals, toxic organics, contaminated sediments, fish consumption advisories and impacted biota due to industrial point sources (pulp mill) and in-place pollutants (contaminated sediments).

Jackfish Bay is one of four Areas of Concern on the Canadian shore of Lake Superior. The other three AOCs are Peninsula Harbour, Nipigon Bay and Thunder Bay and have been grouped together as the "North Shore of Lake Superior Remedial Action Plans" even though each is being developed separately.

The first step in the Remedial Action Plan (RAP) process was the formation of a RAP team, comprised of representatives from the Ontario Ministry of the Environment, Environment Canada, Ontario Ministry of Natural Resources and the Department of Fisheries and Oceans. The RAP team has been charged with the development of a Remedial Action Plan for Jackfish Bay which is a staged process. This document is the first of three stages. Stage I is being prepared in order to define the problem, addressing the following requirements:

- detail existing environmental conditions in order that environmental problems in Jackfish Bay may be defined and described;
- identify beneficial uses that are impaired, the degree of impairment and the geographical extent of impairment within the Area of Concern; and
- define the causes of impairment, providing an assessment of all known sources of pollutants and a description of other potential sources.

In addition to the technical document to address the above, an extensive public participation program has been developed in order to inform the public, improve the plan by gaining information and advice from the public, gain support for plan implementation, and provide a mechanism for accountability to the public.

A number of initiatives were undertaken to raise the profile of the RAP process among the general public through outreach activities. A public consultation program resulted in the formation of a Public Advisory Committee (PAC) consisting of 13 members. Representation from the community includes the Township of Terrace Bay, Kimberly-Clark Canada Inc., community and environmental groups, labour and the general public. The purpose of the PAC is as follows:

- act as a focal point for public consultation and allow effective dissemination of information on the RAP process and environmental concerns;
- provide an additional level of review for RAP documents and remedial options;
- provide an efficient and effective means of ensuring stakeholder input as the RAP is being developed; and

- provide a basis for broad community support for RAP implementation.

The ultimate goal of the public consultation program is to ensure that each RAP addresses local environmental concerns and reflects future water use goals for the community.

2 THE RAP PROCESS

The mechanisms for the development of the Remedial Action Plan for Jackfish Bay have been established through the development of the Great Lakes Water Quality Agreement (GLWQA). This agreement, first signed by Canadian and U.S. governments in 1972, was revised in 1978 and subsequently amended in 1987. The amending protocol in 1987 included an annex which required Canadian and U.S. governments to develop and implement remedial action plans for each of the Great Lakes Areas of Concern. As outlined in the 1987 GLWQA, an Area of Concern is defined as "a geographic area that fails to meet the General or Specific Objectives of the Agreement where such failure has caused or is likely to cause impairment of beneficial use or the area's ability to support aquatic life". Fourteen use impairments are specified in the GLWQA:

i. Restrictions on fish and wildlife consumption;
ii. Tainting of fish and wildlife flavour;
iii. Degradation of fish and wildlife populations;
iv. Fish tumours or other deformities;
v. Bird or animal deformities or reproductive problems;
vi. Degradation of benthos;
vii. Restrictions on dredging activities;
viii. Eutrophication or undesirable algae;
ix. Restrictions on drinking water consumption, or taste and odour problems;
x. Beach closings;
xi. Degradation of aesthetics;
xii. Added cost to agriculture or industry;
xiii. Degradation of phytoplankton and zooplankton populations; and
xiv. Loss of fish and wildlife habitat.

The impairment of any one of these beneficial uses could be sufficient to list an area as an Area of Concern. Using this list as a basis, the IJC has solicited input in the development and refinement of Listing/Delisting Criteria for Great Lakes AOC. In some cases, even with specific criteria outlined, it is difficult to definitively establish whether a beneficial use is impaired. As a consequence, the RAP Team has been required to exercise prudence and extensive consultation with both technical experts within and outside the RAP Team, as well as with the PAC. The Jackfish Bay Remedial Action Plan has used available environmental quality data to compare with the IJC Listing Criteria, in order to determine the impairment status of beneficial uses in Blackbird Creek, Moberly Bay, Jackfish Bay and Tunnel Bay. In addition, violations of existing water quality criteria or effluent requirements have been highlighted even though a direct relationship with an impairment of beneficial uses may not be demonstrated. The public (both individuals and organizations) and various levels and types of government agencies were included throughout the Stage 1 RAP development process in an attempt to reach consensus on the problems in Jackfish Bay.

Annex 2 of the 1987 protocol amending the GLWQA specifies that the RAP should be submitted to the IJC for review and comment at 3 stages. This document represents a completed Stage 1 outlining the definition and description of environmental problems, causes of these use impairments, a description of all known sources of pollutants involved, and an evaluation of other possible sources.

Stage 2 will define the specific goals for the Area of Concern and will describe the remedial and regulatory measures selected to restore beneficial water uses. The Stage 2 RAP will include:

1. an evaluation of remedial measures in place;

2. an evaluation of alternative additional measures to restore beneficial uses and associated costs;

3. selection of additional remedial measures required to restore beneficial uses and a schedule for their implementation; and

4. an identification of the persons, agencies, or organizations responsible for implementation of the selected remedial measures.

Stage 3 of the Jackfish Bay RAP will be submitted when monitoring indicates that identified beneficial uses are restored. This stage of the RAP will include:

1. a process for evaluating the remedial measures implementation and effectiveness; and

2. a description of surveillance and monitoring programs designed to track the effectiveness of remedial measures, and the eventual confirmation of the restoration of the uses.

3 DESCRIPTION OF THE STUDY AREA

The Jackfish Bay AOC is located on the north shore of Lake Superior, approximately 250 km northeast of Thunder Bay. The AOC consists of the reach of Blackbird Creek between the Kimberly-Clark Canada Inc. pulp mill and Jackfish Bay including Lake 'A' and Moberly Lake as well as Jackfish Bay (Figure 1). The Town of Terrace Bay is the closest community to the Jackfish Bay AOC. It has a population of approximately 2,700 and lies to the west of Jackfish Bay outside of the AOC.

Blackbird Creek carries the wastewater discharge from Kimberly-Clark Canada Inc. The Blackbird Creek watershed drains an area of 62 km^2. The creek rises near the town of Terrace Bay and flows in a south-easterly direction for 14 km into the northern tip of Moberly Bay. Historically, Blackbird Creek passed through two shallow lakes referred to as Lake 'A' and Moberly Lake. Lake A originally covered a surface area of 19 ha with depths up to 6.1 m. Moberly Lake is 28 ha in size with a maximum depth of 6.4 m. Lake A was bypassed in the early 1980s because wood fibre had substantially filled it in. Moberly Lake was 0.8 m deep (as of 1982) and has also experienced significant in-filling.

Jackfish Bay contains two inner arms, Moberly Bay on the west, into which Blackbird Creek drains, and Tunnel Bay on the east (Figure 1). A man-made tunnel connects Jackfish Lake with Tunnel Bay. Jackfish Lake receives runoff from a small drainage basin which extends to the north of the lake. The total surface area of Jackfish Bay is 6.4 km^2. The largest islands are Cody Island, which is located in the extreme southwest of Moberly Bay; Bennett Island, located in southeastern Moberly Bay; and St. Patrick Island, which is located near the eastern shore of Jackfish Bay.

Mean daily temperatures in the region are -13.3 °C in January and 15 °C in July. Mean daily maxima and minima are -7.8 °C and -18.9 °C in January and 21.1 °C and 10.0 °C in July. Recorded mean annual rainfall

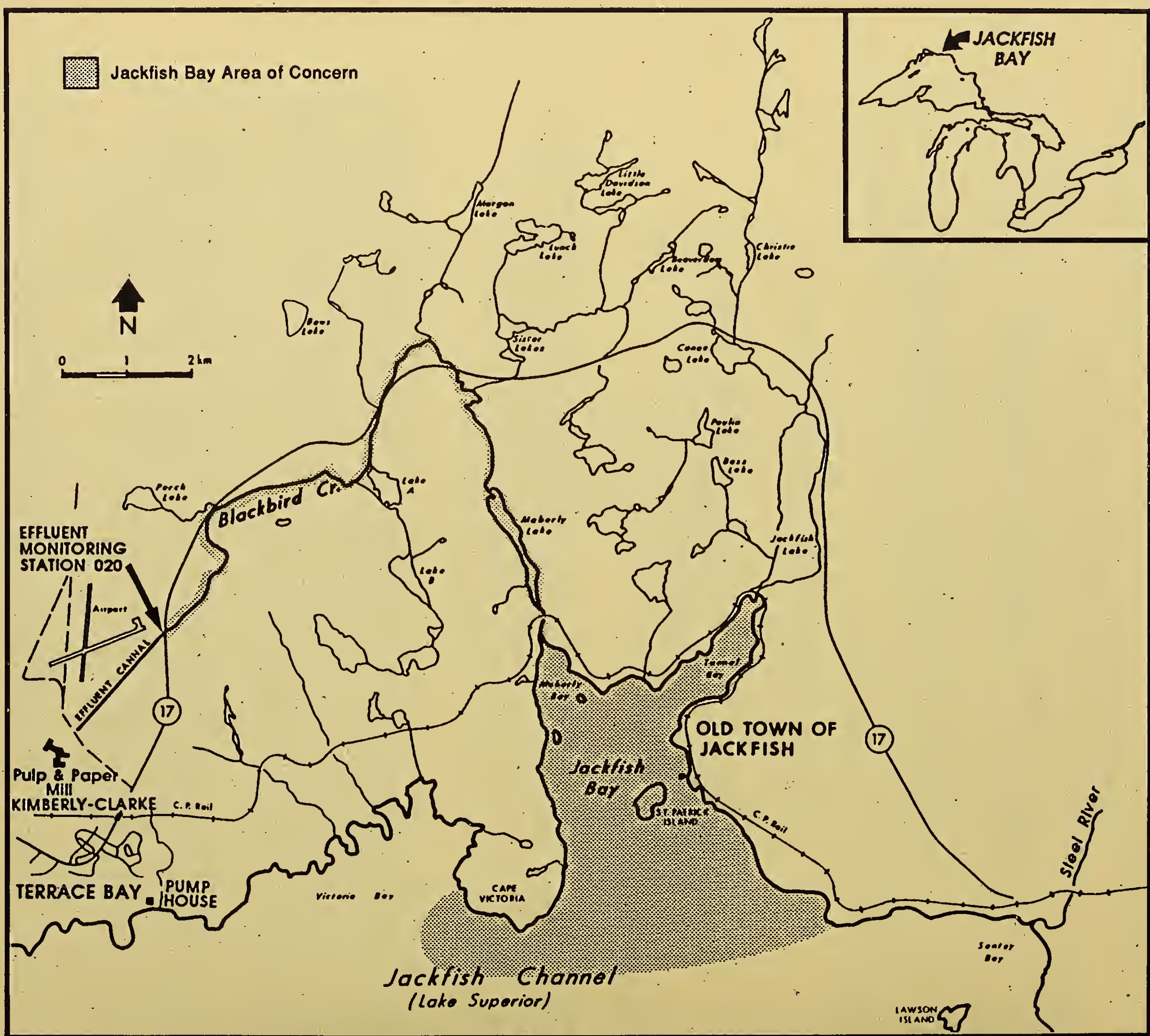


Figure 1

Location map of the Jackfish Bay Area of Concern

is 787.4 mm with a mean annual snowfall of 243.8 cm. Precipitation is relatively low in winter and high in summer.

The area lies within the Abitibi Upland Unit of the James Physiographic Region. This unit is described as having a broad rolling surface and consisting of crystalline Archean rocks of the Canadian Shield. The bedrock geology of the northern and western shores of Jackfish Bay is dominated by massive crystalline igneous rocks consisting of granodiorite to granite. The southeastern shore of Jackfish Bay consists of mafic to intermediate metavolcanic rocks. Minor metasedimentary rocks (metamorphosed sedimentary strata) also occur within this complex. Glacial deposits consist mostly of a shallow sandy till ground moraine which overlies the lower portions of bedrock outcrops. Localized deposits of sandy glacial outwash and glaciolacustrine deltaic sediments also occur.

The Jackfish Bay AOC lies within the Superior Forest Section of the Boreal Forest Region. Forests of white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), white birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*) are found in the valleys. The same species, but with birch more prominent and some black spruce (*Picea mariana*), is found on the thin till slopes and tops of low hills. Jack pine (*Pinus banksiana*), white birch and poor quality black spruce, are characteristic of higher rocky elevations and coarser valley soils. Lowland areas support high quality stands of black spruce along with tamarack (*Larix laricina*) and eastern white cedar (*Thuja occidentalis*).

Wildlife found in the area of Jackfish Bay are species well adapted to the harsh climatic conditions found there. Common species include: moose, deer, timber wolf, fox, lynx, black bear, mink, fisher, martin, muskrat, beaver, porcupine, skunk, snowshoe hare and red squirrel. Shrew, mice and vole populations are also found in the District, as well as a variety of upland game birds and songbirds.

4 LAND USE

There are no industrial, commercial, residential or agricultural land uses within the watershed of the Jackfish Bay AOC. Cottages have been constructed along the east shore of Jackfish Bay at the former town of Jackfish. The Kimberly-Clark Canada Inc. pulp mill lies to the northwest of the Town of Terrace Bay which is located west of Jackfish Bay. There are no industrial or municipal landfills within the AOC. The only landfill is a small site operated by the Ontario Ministry of Natural Resources located near the cottage community of Jackfish. It receives only domestic refuse and is not considered a potential hazard to the AOC.

5 WATER RESOURCE USE

Process water for the pulp mill and domestic water for the Town of Terrace Bay is obtained from a common intake located in open Lake Superior, approximately 10 km west of Jackfish Bay. The combined intake currently approaches 143,850 m^3/day. Hays Lake, located northwest of the Town of Terrace Bay, provides an alternate water supply.

Process water from the Kimberly-Clark Canada Inc. pulp mill is discharged into Blackbird Creek which flows over a distance of 14 km to Moberly Bay in Jackfish Bay. During 1990 the average effluent flow from the mill was 94,000 m^3/day. This represents the only point source discharge within the Jackfish Bay AOC.

Municipal wastes from the Township of Terrace Bay are treated in part by a small extended aeration facility and polished through an exfiltration lagoon, and in part by passing through two septic tanks followed by an exfiltration lagoon. Both lagoons lie adjacent to Lake Superior, immediately south of the townsite and removed from Jackfish Bay. Their is no direct discharge from the lagoons.

Water depth in Jackfish Bay generally increases abruptly from the rugged shorelines to depths of 10 to 50 m. Littoral areas are limited in extent, forming extremely narrow bands along the shoreline and, as a result, wetlands are not present in Jackfish Bay. Nearshore fish spawning and nursery habitat is restricted to isolated pockets, primarily located in Tunnel Bay and around Cody and Bennett Islands. Jackfish Lake is connected to the northern tip of Tunnel Bay by a channel approximately 15 m in length. The lake provides spawning and nursery habitat for a number of resident warmwater species in addition to migrants from Jackfish Bay. Jackfish Bay species which spawn in Jackfish Lake or its tributaries include walleye (*Stizostedion vitreum*), northern pike (*Esox lucius*), rainbow trout (*Oncorhynchus mykiss*), pink salmon (*O. gorbuscha*) and suckers (*Catostomus* sp.). Major lake trout (*Salvelinus namaycush*) spawning grounds were historically located in Moberly Bay and along the shore of Lake Superior adjacent to Jackfish Bay. Lake Whitefish (*Coregonus clupeaformis*) spawning grounds occur along Lake Superior's shore immediately east and west of Jackfish Bay. Blackbird Creek was noted as a brook trout (*Salvelinus fontinalis*) stream prior to the start-up of the mill in 1948.

Commercial fishermen first settled in Jackfish Bay during the 1870s and the commercial fishery industry was well established by the mid 1880s. Jackfish Bay was noted as an excellent port, but, fishing was never extensive in the area as the adjacent shoreline was rugged and storms could be severe. The fishery was characterized as a rowboat fishery with an annual catch of approximately 14,500 kg of lake trout and 6,000 kg of whitefish between 1895 and 1898. Commercial fishing activity peaked during the early 1900s, when approximately 40 families were permanent residents of the former Town of Jackfish (Figure 1). However, since the early 1950s, water pollution, sea lamprey predation, and heavy exploitation depleted fisheries stocks in Lake Superior. Although there is no commercial fishery located within Jackfish Bay, two licensed commercial fishing operations utilize offshore areas in Lake Superior beyond the Slate Islands. The total commercial harvest in 1985 amounted to 5,082 kg which was valued at $5,727. Lake trout, lake whitefish, chub (*Coregonus* sp.) and lake herring (*Coregonus artedii*) are the four prime commercial species.

Sport fishing in Jackfish Bay declined dramatically during the 1950s and has remained depressed under current conditions. Lake trout spawning shoals appear to have been adversely affected by organic material in the discharge from the Kimberly-Clark Canada Inc. mill. Electrofishing surveys found few species and low numbers of fish in Moberly Bay as well as increasing numbers and species diversity with increasing distance from the mill outfall.

The Jackfish Bay AOC is an attractive location for recreational use. However, Lake Superior's inherent cold water conditions, poor aesthetics related to the effluent from Blackbird Creek, and limited access restrict traditional water activities. Water based recreational activities are restricted to scuba diving by local residents. The wreck of the Rappahannock, a 94 m bulk freighter which sank in 1911 in Tunnel Bay, is a popular local dive site.

6 ENVIRONMENTAL CONDITIONS

6.1 Water Quality

Water quality surveys undertaken during 1970, 1981 and 1987/88 indicated a plume of contamination in Jackfish Bay resulting from the discharge of effluent from the Kimberly-Clark pulp mill via Blackbird Creek. Surface waters, situated above the hypolimnion layer, are most affected in terms of higher concentrations and more frequent exceedences of PWQOs and GLWQA Specific Objectives than bottom waters. Although the extent and impact of the plume varies depending on wind and current direction, the most heavily impacted zone includes Blackbird Creek, all of Moberly Bay and the northern and western portions of Jackfish Bay. Nearshore waters of Lake Superior to the west of Jackfish Bay are also affected by the plume as shown by stations located offshore of Cape Victoria and by bacterial surveys. Elevated densities of several bacterial species occurred in densities exceeding PWQOs or IJC recommended levels as far west as Pumphouse Bay

south of the Town of Terrace Bay. Although Tunnel Bay is mostly outside the plume, guideline exceedences (particularly metals and bacteria) occur occasionally due to individual wind events moving the surface plume to the northeast.

Table A provides a summary of ambient water data for the Jackfish Bay AOC. Data ranges are for open water stations in Moberly, Jackfish and Tunnel Bays only. Data for Blackbird Creek are provided separately in Section 3.4. Table A also indicates where exceedences of objectives have occurred based on the most recent water quality surveys which were undertaken during July and August 1987 and July 1988.

These surveys identified concentrations of contaminants resulting in exceedences of PWQOs and/or GLWQA Specific Objectives in Moberly, Jackfish or Tunnel Bays for turbidity (secchi disc), dissolved oxygen, pH, total phosphorus, total coliform bacteria, fecal coliform bacteria, aluminum, beryllium, cadmium, chromium, copper, iron, mercury, nickel, lead, zinc and dehydroabietic acid. The dissolved oxygen objective was also violated during 1990 studies. The IJC recommended guideline for *Pseudomonas aeruginosa* was also exceeded in Moberly and Jackfish Bays. Total phenolics and pentachlorophenol were exceeded during the 1981 surveys in Moberly Bay. Most exceedences occur in the upper half of Moberly Bay, however, exceedences occur regularly for some metals and bacteria in much of Jackfish Bay and occasionally in Tunnel Bay.

The environmental condition of Blackbird Creek has been severely degraded. During low flow conditions, up to 90 percent of the flow in the creek represents effluent from the Kimberly-Clark Canada Inc. pulp mill. Ambient objectives were also exceeded in Blackbird Creek for many of the same parameters as noted for Moberly and Jackfish Bays (Table A) as well as 2,3,4,5-tetrachlorophenol, 2,4,6-trichlorophenol, pentachlorophenol, τ-chlordane, endrin, endosulphan I, endosulphan II, heptachlor, o,p-DDT, p,p-DDD, p,p-DDE, p,p-DDT and *Escherichia coli*.

6.2 Bottom Sediment Quality

The results of geophysical investigations of sediments from the Jackfish AOC during 1987 and 1988 identified the presence of three depositional basins in which fine-grained (mud) sediments dominated. These basins correspond to Moberly, Jackfish and Tunnel Bays. The sediments of Moberly Bay have the highest percentage of organic material and consequently the most reducing conditions. The presence of the organic material is attributed primarily to the mill effluent which enters via Blackbird Creek. The sediments of the three basins are variously contaminated due to a variation in sources and to processes which affect their accumulation and availability.

Table B provides a summary of the most commonly detected contaminants in surficial sediments collected at stations in Moberly, Jackfish and Tunnel Bays. The locations where station means exceeded guidelines are also indicated. Contaminants which exceeded either the Open Water Dredged Material Disposal Guidelines and/or the Lowest Effect Level of the Provincial Sediment Quality Guidelines, based on surveys undertaken during 1987 and 1988 include: oil and grease, total organic carbon, total phosphorus, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, hexachlorobenzene and total PCBs. TKN measured in 1981 also exceeded guidelines. In addition, high concentrations of certain phenolic compounds, resin and fatty acids, and dioxins and furans, for which no guidelines are available, contaminate sediments within the AOC.

Contaminants which are attributed to the Kimberly-Clark effluent based on their temporal or spatial distribution patterns, either currently or historically, include total organic carbon, TKN, mercury, zinc, total PCBs, hexachlorobenzene, phenolic compounds, resin and fatty acids and tetrachlorodibenzofurans. The most likely sources for the higher chlorinated dibenzo-p-dioxins and furans, and certain metals (cadmium and copper) are diffuse and point sources remote from the AOC and contributed via atmospheric deposition.

Table A Contaminant inventory summary in ambient water from the Jackfish Bay Area of Concern (1987/88) with comparisons to the Provincial Water Quality Objectives (PWQO) and the Great Lakes Water Quality Agreement (GLWQA) objectives (Sherman 1991).

Parameter	Objective/Guideline		Detection Limit (DL)	RAP Data*		Location of Exceedence
	PWQO	GLWQA		# > DL /# Samples†	Range of Values*	
Physical Parameters:						
Tubidity (FTU)	<10% secchi depth decrease	-	-	452/452	0.20 - 460.0	MB
pH	6.5 - 8.5	-	-	452/452	5.40 - 8.00	MB
Total Alkalinity (mg/L)	25% change	-	-	452/452	4.0 - 220.0	-
Nutrients and Metals (mg/L):						
Total Phosphorus (μg/L)	20	-	2	432/454	1 - 770	MB JB BC
Aluminum	0.075	-	<0.003 - <0.1	195/297	<0.003 - 2.10	MB JB BC
Arsenic	0.1	50	<0.001	28/314	<0.001 - 0.018	-
Beryllium	0.010	-	<0.0005 - <0.05	1/309	<0.001 - 0.05	MB
Cadmium	0.0002	0.0002	<0.0002 - <0.015	21/309	<0.0002 - 0.040	MB JB
Chromium	0.10	0.050	<0.005 - <0.10	120/309	<0.001 - 0.13	MB
Copper	0.005	0.005	<0.0005 - <0.10	111/309	<0.001 - 0.41	MB JB TB
Iron	0.300	0.300	<0.001 - <0.10	174/309	<0.001 - 2.60	MB BC
Lead	0.020	0.020	<0.005 - <0.15	38/309	<0.003 - 0.22	MB JB TB
Mercury (μg/L)	0.2	0.2	0.01	94/319	<0.01 - 0.07	MB JB
Manganese	-	-	<0.0005 - <0.01	264/309	<0.001 - 0.59	elevated in MB
Nickel	0.025	0.025	<0.001 - <0.10	22/309	<0.001 - 0.1	MB
Zinc	0.030	0.030	<0.0005 - <0.10	134/309	<0.001 - 0.38	MB JB BC
Bacteria (cnt/100 mL) Geometric Mean:						
Total Coliform	1000	-	<4 - <10	356/377	<4 - 4,600,000	MB JB BC
Escherichia coli	-	23‡	<3	48/81	<3 - 1100	BC
Pseudomonas aeruginosa	-	1	<1 - <100	23/63	<1 - 2800	MB JB BC

Table A (Cont'd)

Parameter	Objective/Guideline		Detection Limit (DL)	RAP Data*		Location of Exceedence
	PWQO	GLWQA		# > DL /# Samples†	Range of Values*	
Polychlorinated Phenols (ng/L):						
2,3,4,5-tetrachlorophenol	1,000	-	<1000 - <50000	0/161	ND	BC
2,4,6-trichlorophenol	18,000	-	<1000 - <50000	24/161	ND-75,000	BC
Pentachlorophenol	500	-	<1000 - <50000	0/160	ND	BC
Resin and Fatty Acids (μg/L):						
Dehydroabietic Acid	12.0 (pH=7.5)	-	10	1/36	10 - 30	MB
Pesticides (ng/L):						
τ-Chlordane	60.0	-	<2.0 - <20.0	2/265	ND-100.0	BC
Endrin	2.0	-	<4.0 - <40.0	6/265	ND-30.0	BC
Endosulphan II	3.0	-	<4.0 - <40.0	2/265	ND-30.0	BC
Heptachlor	1.0	-	<1.0 - <10.0	1/265	ND-15.0	BC
OP-DDT	3.0	-	<5.0 - <50.0	2/265	ND-80.0	BC
PP-DDD	1.0	-	<5.0 - <50.0	10/265	ND-80.0	BC
PP-DDE	1.0	-	<1.0 - <10.0	6/265	ND-14.0	BC
PP-DDT	1.0	-	<5.0 - <50.0	4/265	ND-55.0	BC

MRA Minimal Recordable Amount (Detection Limit)
MB Moberly Bay
JB Jackfish Bay
TB Tunnel Bay
BC Blackbird Creek

* Data Set Range - Ranges provided for open water stations in JB/MB/TB. Blackbird Creek data reported separately in Section 3.4.
† Number of samples are above the maximum detection limit.
‡ IJC Recommended Guideline

Table B Contaminant inventory summary for surficial sediment in the Jackfish Bay Area of Concern (1987/88) with comparison to the open water dredged material disposal guidelines (OWDG) and the Provincial sediment quality guidelines (PSQG).

Parameter	OWDG (µg/g)	PSQG (µg/g)		Detection Limit (DL) (µg/g dry)	Rap Data		
		LEL	SEL		# > DL /# samples	Range (µg/g)	Location of Exceedences*
Metals:							
Mercury	0.30	0.2	2	0.01	96/102	0.01-9.1	MB
Aluminum	-	-	-	TBP	102/102	4,300-18,000	-
Cadmium	1.0	0.6	10	0.1	102/102	0.2-2.1	MB JB TB
Arsenic	8	6	33	TBP	102/102	0.55-14.0	TB
Chromium	25	26	110	1.0	102/102	2.0-81.0	MB JB TB
Copper	25	16	110	1.0	102/102	4.3-68	MB JB TB
Iron	10,000	20,000 2%	40,000 4%	1.0	102/102	7,900-31,000	MB JB TB
Manganese	-	460	1,100	TBP	102/102	29-260	TB
Nickel	25	16	75	TBP	102/102	7.0-31.0	MB JB TB
Lead	50	31	250	2.0	102/102	2.9-50.0	TB
Zinc	100	120	820	TBP	102/102	29-260	MB
Nutrients and Organics:							
Total Phosphorus	1,000			TBP	102/102	300-1,580	MB
Total Kjeldahl Nitrogen	2,000	550	4,800	TBP	TBP	200-7,000†	MB JB† TB ML
Phenol	-	-	-	0.01-0.05	16/93	ND-0.30	-
Solvent Extractables (Oil and Grease)	1,500	-	-	TBP	97/97	21-58,300	MB JB TB
TOC	-	10,000	100,000	TBP	102/102	5,000-25,000	MB JB TB
Chlorinated Organics:							
Total PCBs	0.05	0.07	‡	0.02	4/97	ND-0.28	MB
Hexachlorobenzene	-	0.01		.001	43/100	ND-0.040	MB
Resin and Fatty Acids:							
Dehydroabietic Acid	-	-	-	0.005	53/77	ND-4.305	elevated MB TB

Note Where values were recorded as being "less than" the minimum amount measurable, half the "less than" value was used for calculation of the mean.

* Exceedences based on mean concentrations at stations in Moberly Bay (MB), Jackfish Bay (JB) and Tunnel Bay (TB) and idividual samples (TKN only) for Moberly Lake (ML).

† 1981 Data.

‡ Dependant on TOC concentration of sediment.

TPB To Be Provided

Cadmium and copper concentrations may also reflect local geochemical conditions along with chromium, iron, nickel and manganese. The distribution patterns of total phosphorus, arsenic and lead do not clearly identify likely sources.

The presence of PCBs in sediment within Moberly Bay may be due to their former use in electrical equipment at the Kimberley-Clark mill. Detectable concentrations of organochlorine pesticides were found only in Moberly Bay sediments. PAHs were distributed throughout the study area which likely indicates atmospheric sources to the AOC.

Although the data are not sufficient to identify statistically significant trends over time, a comparison of data collected in 1981 with data collected in 1987/88 and the historical record identified in sediment cores from Moberly Bay suggest certain trends. Generally, concentrations of oil and grease, total phosphorus, and manganese appear to be fairly constant over time. Total organic carbon, cadmium, copper and zinc appear to be increasing in concentration whereas mercury and total PCBs are decreasing.

6.3 Biota Quality

The biota within the Jackfish Bay AOC, including benthic macroinvertebrates and sport fish, have been impacted as a result of the mill effluent discharged through Blackbird Creek. Densities of benthic macroinvertebrates tend to be lowest along the western portion of Moberly and Jackfish Bays due to the influence of the effluent plume from Blackbird Creek. Between 1969 and 1987, maximum densities of pollution tolerant organisms (tubificids) increased by more than six times while densities of pollution intolerant organisms (*Pontoporeia hoyi*) decreased dramatically. During this period the extent of tubificids also increased in concert with a decrease in the extent of *P. hoyi*. Whereas in 1969 only the central portion of Moberly Bay and the northwestern portions of Jackfish Bay were affected, by 1987 the density of *P. hoyi* had decreased in Tunnel Bay as well as the eastern and central portions of Jackfish Bay.

The extent of benthic communities identified as impaired also increased between 1969 and 1975. Between 1975 and 1987 the extent increased further and an additional impaired community was identified. Impaired communities were found to occur in sediments which had the highest mean concentrations of cadmium, copper, lead, zinc and TKN as well as high levels of fibre (loss on ignition). The impact to benthic macroinvertebrates in the Jackfish Bay AOC have been attributed to the Kimberly-Clark mill effluent.

Changes to the structure of the fish community have been mostly related to causes such as harvesting, the sea lamprey and the introduction of exotic species. However, recent studies of lake whitefish, longnose sucker and white sucker from Jackfish Bay have revealed several effects which researchers have attributed to the mill effluent. These include slower growth, smaller gonads, lower fecundity with age, absence of secondary sex characteristics in males, failure of females to show increase in egg size with age, decreased estradiol and testosterone levels and increased mixed oxidase function activities in comparison to noncontaminated reference fish. The increased MFO activity can be attributed to the presence of organic contaminants and has been associated with dioxins, furans and resin acids present in the mill effluent. The addition of secondary treatment in October 1989 reduced the toxicity of the effluent, but, has not resulted in a reduction of MFO activity in white suckers from Jackfish Bay.

Table C summarizes the contaminant data for fish and other biota in the Jackfish Bay AOC based on collections from 1987 to 1989. The body burdens of native benthos (*Mysis relicta*), introduced mussels (*Elliptio complanata*) and white suckers from Jackfish Bay indicate a pattern of dioxin and furan bioaccumulation which suggests the mill effluent as the major source. This includes the bioaccumulation of tetrachlorodibenzo-p-dioxins (including the highly toxic 2,3,7,8-TCDD congener) and tetrachlorodibenzofurans, contributed mostly by the effluent, in greater concentrations than the higher chlorinated dioxins, contributed by effluent and atmospheric deposition. The higher chlorinated compounds

Table C Frequency of detection and concentrations ($\mu g/g$) of contaminants in lake trout, white suckers, introduced mussels (*Elliptio complanata*), opossum shrimp (*Mysis relicta*), and young-of-the-year spottail shiners collected in 1987 to 1988 from Jackfish Bay.

Parameter	Great Lakes Water Quality Agreement Specific Objective	National Health & Welfare Regulatory Limit	Detection Limit (DL)	# > DL /# Samples	Range
Lake Trout (1989)*					
Mercury#	0.5†	0.5	0.01	20/20	0.6-0.38
Total PCBs	0.1‡	2.0	0.02	20/20	0.04-0.44
Mirex	Substantially absent	0.1	0.005	0/20	ND
Hexachlorobenzene	-	0.1	0.001	16/20	ND-0.004
pp-DDE	-	-	0.001	19/20	ND-0.117
α BHC	-	-	0.001	18/20	ND-0.009
γ-BHC	-	-	0.001	8/20	ND-0.001
α-chlordane	-	-	0.002	20/20	0.002-0.017
γ-chlordane	-	-	0.002	19/20	ND-0.007
pp-DDD	-	-	0.002	5/20	ND-0.001
Toxaphene	-	-	0.2	18/20	ND-1.47
2,3,7,8-TCDD	-	0.000020	0.000002	5/5	0.0000029-0.0000113
1,2,3,7,8-5PCDD	-	-	"	5/5	0.0000036-0.0000055
1,2,3,4,7,8-6HCDD	-	-	"	0/5	ND
1,2,3,6,7,8-6HCDD	-	-	"	0/5	ND
1,2,3,7,8,9-6HCDD	-	-	0.000002	0/5	ND
1,2,3,4,6,7,8-7HCDD	-	-	"	1/5	ND-0.0000011

Table C (cont´d)

Parameter	Great Lakes Water Quality Agreement Specific Objective	National Health & Welfare Regulatory Limit	Detection Limit (DL)	# > DL /# Samples	Range
8OCDD	-	-	"	5/5	0.0000016-0.0000035
2,3,7,8-TCDF	-	-	"	5/5	0.000020-0.000058
1,2,3,7,8-5PCDF	-	-	"	5/5	0.0000023-0.0000080
2,3,4,7,8-5PCDF	-	-	"	5/5	0.0000015-0.0000036
1,2,3,4,7,8-6HCDF	-	-	"	0/5	ND
1,2,3,6,7,8-6HCDF	-	-	"	0/5	ND
1,2,3,7,8,9-6HCDF	-	-	"	0/5	ND
2,3,4,6,7,8-6HCDF	-	-	"	0/5	ND
1,2,3,4,6,7,8-7HCDF	-	-	"	1/5	ND-0.0000022
1,2,3,4,7,8,9-7HCDF	-	-	"	0/5	ND
8OCDF	-	-	"	0/5	ND
White Suckers (1988)$					
2,3,7,8-TCDD	-	0.000020	0.000002	4/4	0.0000027-0.0000120
2,3,7,8-TCDF	-	-	0.000002	4/4	0.0000210-0.0000650
Elliptio complanata (1988)					
2,3,7,8-TCDD	-	0.000020	0.000002	1/4	ND-0.0000016
2,3,7,8-TCDF	-	-	0.000002	4/4	0.0000095-0.0000140
Mysis relicta (1987)					
2,3,7,8-TCDD	-	0.000020	0.000002	2/2	0.0000080-0.0000090
2,3,7,8-TCDF	-	-	0.000002	2/2	0.0000460-0.0000490

Table C (cont'd)

Parameter	Great Lakes Water Quality Agreement Specific Objective	National Health & Welfare Regulatory Limit	Detection Limit (DL)	# > DL /# Samples	Range
Spottail Shiners (1988)**					
Total PCBs	0.1	2.0	0.02	0/3	ND
DDT	1.0‡	5.0	0.002	0/3	ND
Mirex	substantially absent	0.1	0.005	0/3	ND
chlordane	-	-	0.002	0/3	ND
BHC	-	-	0.001	0/3	ND
Hexachlorobenzene	-	0.1	0.001	0/3	ND
Octachlorostyrene	-	-	0.001	0/3	ND

ND not detected.
* data courtesy of the OMOE/OMNR Sportfish Consumption Program.
† Ontario guideline for protection of human consumers of fish (skinless filet).
‡ protection of birds and animals which consume fish (whole fish).
§ data from Sherman et al. (1990).
# no consumption is recommended if the level for mercury exceeds 1.5 ppm.
** data from Suns et al. (1991).

occur in sediment at concentrations comparable or higher than the tetrachlorodibenzo-p-dioxins and the tetrachlorodibenzofurans, however, the latter appear to be preferentially accumulated by biota.

Although fish consumption advisories were previously in effect due to mercury and PCB concentrations, these restrictions have been removed. The removal is based on collections during 1989 which indicated that all contaminants were below the Ontario consumption guidelines. However, consumption of lake trout greater than 55 cm is tentatively recommended for restricted consumption due to the sum of dioxins and furans expressed as toxic equivalents of 2,3,7,8-tetrachlorodibenzo-p-dioxin. The only guideline exceedence in either sport fish or young-of-the-year spottail shiners collected in 1989 and 1988, respectively, is the GLWQA Specific Objective for the protection of piscivorous wildlife from PCBs. This objective was exceeded by up to four times by the maximum concentration measured in lake trout collected during 1989 (Table C).

7 SOURCES

The sources of chemicals which impact on water, sediment and biota quality within the Jackfish Bay AOC include one point source and several nonpoint sources. The only point source is the effluent from the Kimberly-Clark Canada Inc. pulp mill located in Terrace Bay. There are no other industrial or municipal dischargers to the AOC.

Nonpoint sources include atmospheric, in-place sediment contamination (from natural sources as well as Kimberly-Clark effluent) and spills. Other potential nonpoint sources such as urban and agricultural runoff, groundwater contamination from waste sites or shipping do not occur in the Jackfish Bay AOC.

Table D summarizes loadings data and monthly exceedences of Control Order limits for various years between 1973 and 1990. Kimberly-Clark Canada Inc. is currently meeting its Control Order requirements for BOD_5, suspended solids, adsorbable organic halides (AOX), total phosphorus and effluent toxicity. The addition of the secondary treatment facility in October 1989 appeared to be particularly efficient with regard to biological oxygen demanding substances, phenolics, and resin and fatty acids. Lower effluent concentrations of resin and fatty acids has reduced the toxicity of the effluent (not acutely lethal in 1990) and resulted in lower concentrations of these acids in surface waters of Moberly Bay (1990 survey). The PWQO for dehydroabietic acid was exceeded in Moberly Bay during 1987/88. However, in 1990, this acid was not detected.

Although significant reductions have been achieved in the loadings of BOD_5 from the Kimberly-Clark effluent, the occurrence of PWQO violations for dissolved oxygen as recently as 1990 (Section 3.1) suggests that further reductions may be required. Alternatively, there may be ongoing contributions of biological oxygen demanding substances, due to historical deposition in the Blackbird Creek System and/or Moberly Bay.

Most of the water, sediment and biota quality data were collected prior to the secondary treatment facility becoming operational and, hence, it is not known if there has been any improvement with regard to ambient guideline exceedences other than dissolved oxygen. Mean effluent concentrations of aluminum, copper and mercury appear to have declined since 1988. However, the mill effluent is likely the main source of most conventional parameters, bacteria, nutrients, metals, organochlorine pesticides and phenolic compounds which have been found to exceed ambient guidelines.

The source of bacteria, particularly *Escherichia coli* and *Pseudomonas aeruginosa*, is of concern especially as these organisms have exceeded recommended health guidelines in Moberly and Jackfish Bays (Section 3.1). They may originate from domestic sewage within the mill.

Table D Average annual effluent loadings of monitored pollutants in Kimberly-Clark Canada Inc. effluent and number of monthly exceedences (in brackets for 1986 to 1989 only)*. All loadings in kg/day unless otherwise noted.

	1973	1981	1986	1987	1988	1989	1990†
Flow (m^3/d)	202,600	113,800	110,333	115,000	117,100	109,344	94,900
BOD_5 (t/d)	30,100	30,600	29,550(0)	24,833(NA)	26,225(5)	17,633(0)	1,400
Total Phosphorus	NA	NA	76.35(1)‡	64.63(0)	62 (0)	NA	NA
Suspended Solids	6,700	5,400	5,345(0)	5,568(2)	4,863(0)	3,878(0)	4,100
Toxicity(LC_{50})**	NA	10.0	12.5-45.6	15.1-42.8	11.8-41.4	25.3-51.0	non-lethal

* data taken from OMOE annual Reports on the Industrial Direct Discharges in Ontario (OMOE 1987, 1988, 1989, 1991b).

† Post-secondary treatment, data from OMOE files.

‡ exceedence considered an anomaly as measurement is not consistent with typical mill levels.

** % effluent required to kill 50% of the test fish.

NA Not available

The origin of organochlorine pesticides in the mill effluent is not known. These chemicals may be derived from logs which are processed in the mill. Contamination of the logs may reflect atmospheric sources including aerial spraying.

Additional sources of certain contaminants to the Jackfish Bay AOC include atmospheric sources and natural geological sources. Atmospheric pathways are believed to contribute loadings of PCBs, PAHs, higher chlorinated dioxins and furans (particularly octachlorodibenzo-p-dioxins and octachlorodibenzofurans), cadmium, lead, mercury and vanadium to the AOC. Studies of atmospheric precipitation in the Great Lakes Basin suggest that the upper lakes, such as Lake Superior, receive the greatest proportion of their loadings of lead and PCBs from the atmosphere. This is due to their large surface areas and lack of local industrial and urban sources. However, it is not known precisely what proportion of these contaminants may be contributed to the Jackfish Bay AOC from local sources. Limited data for local atmospheric emissions indicate that aromatic compounds, primarily 1-isopropyl-4-methylbenzene are contributed from the Kimberly-Clark pulp mill.

Bottom sediments in Lake Superior, outside the zone of impact by the Kimberly-Clark Canada Inc. pulp mill effluent, have been found to have concentrations of chromium, copper, iron and nickel which exceed the Lowest Effect Level of the Provincial Sediment Quality Guidelines. Manganese concentrations exceeded the No Effect Level. Hence, it is likely that natural sediment geochemistry is responsible for a large proportion of the conentrations of these parameters in bottom sediments of the Jackfish Bay AOC.

The availability and impact of chemicals in sediments with regard to water and biota in this area has not been thoroughly investigated. Sediments from Moberly Lake were lethal to both *Hyallela* (LC34) and chironomid larvae (LC42). Body burdens of dioxin and furan congeners in benthic fauna (mussels and opossum shrimp) of Moberly Bay suggest that sediment concentrations, particularly of tetrachlorodibenzo-p-dioxins and tetrachlorodibenzofurans, may be impacting the benthos. In addition, the draft Provincial

Sediment Quality Guideline Lowest and Severe Effect Levels are biologically based and, hence, exceedences of these levels results in impairment to the majority of benthic species.

There are no spills within the Jackfish Bay AOC as there are no industrial or other developments within the watershed. Spills are confined to the area of the Kimberly-Clark Canada Inc. mill site and only impact the AOC if they reach the effluent canal which drains to Blackbird Creek. In this regard, flows in the acid and alkaline sewers, on occasion, bypass the treatment system resulting in untreated effluent reaching Blackbird Creek. As of September 8, there were 12 bypass events during 1991. These events were primarily due to equipment failures (O-Rings, seized valves) and power outages which shut down the pumping equipment. Because the volume of effluent which bypasses the system is not known, it is not possible to determine the impact of these events on the AOC. However, it is expected that these events contribute to contamination of Jackfish Bay and, hence, their occurrence should be minimized.

8 ENVIRONMENTAL CONCERNS/USE IMPAIRMENTS

Table E summarizes information on each use impairment category for the Jackfish Bay AOC. The status of each use impairment category is identified as impaired, not impaired or requiring further assessment.

8.1a Restrictions on Fish Consumption

Consumption of lake trout up to 65 cm in length is currently unrestricted with regard to mercury and PCB concentrations. The consumption of whitefish, cisco and white sucker to 45 cm in length is also unrestricted. However, the guide indicates that consumption of lake trout greater than 55 cm could be restricted due to concentrations of dioxins and furans expressed as toxic equivalents of 2,3,7,8-tetrachlorodibenzo-p-dioxin.

8.1b Restrictions on Wildlife Consumption

There are currently no restrictions for the consumption of wildlife form the Jackfish Bay AOC.

8.2 Tainting of Fish and Wildlife Flavour

No reports of tainted fish or wildlife by the public or the fisheries/wildlife personnel.

8.3a Dynamics of Fish populations

Blackbird Creek fish populations have been totally eliminated as a result of the pulp mill effluent. Similarly, fish populations in Moberly Bay, in the vicinity of Blackbird Creek, have been severely reduced. Prior to installation of secondary effluent treatment by the mill (October 1989), toxicity tests on surface waters up to 1.5 km from the creek mouth resulted in 100 percent fish mortality. Results from toxicity testing since this time indicated that mill effluent is no longer acutely lethal.

Degraded water quality, harvesting, the sea lamprey and introduction of exotic fish species have directly depressed fisheries production in Jackfish Bay. Species diversity and densities in the northern portion of Moberly Bay are among the lowest found in Lake Superior. The zone of influence, which radiates south from the mouth of Blackbird Creek, has diminished fisheries potential in the entire Jackfish Bay area, although the degree of impact has not been determined.

Table E Summary of impairments to Great Lakes Water Quality Agreement beneficial uses within the Jackfish Bay Area of Concern. Impairment status is defined as impaired (I), not impaired (NI) or requires further assessment (A) and is based on data collected during from 1987 to 1990.

GLWQA Impairment of Beneficial Use	Status of Impairment	Conditions In Jackfish Bay
Restrictions on Fish and Wildlife Consumption		
Restrictions on Fish Consumption	A	The 1991 "Guide to Eating Ontario Sport Fish" notes that the consumption of lake trout greater than 55 cm in size may need to be restricted due to concentrations of dioxins and furans expressed as toxic equivalents to 2,3,7,8-tetrachlorodibenzo-p-dioxin.
Consumption of Wildlife	NI	No restrictions exist
Tainting of Fish and Wildlife Flavour	NI	There have been no reports of tainting by the public or by fisheries/wildlife personnel
Degradation of Fish and Wildlife Populations		
Dynamics of Fish Populations	I	Lake trout populations have declined since the mid 1950s for a number of reasons including the accidental introduction of sea lamprey, the start-up of the Kimberly-Clark mill, over-harvesting and the introduction of exotic fish species. Blackbird Creek fish populations have been totally eliminated as a result of the pulp mill effluent. Similarly, fish populations in Moberly Bay, in the vicinity of Blackbird Creek, have been severely reduced.
Body burdens of Fish	I	White suckers have bioaccumulated TCDDs and TCDFs from water and sediment contaminated by the mill effluent. Lake trout have low concentrations of mercury, hexachlorobenzene and several chlorinated pesticides. The GLWQA Specific Objective for the protection of piscivorous wildlife from PCBs was exceeded in lake trout collected in 1989.
Dynamics of Wildlife Populations	A	Blackbird Creek may attract wildlife during the spring months as the moderating influence of warm creek water tends to accelerate greening of creek side vegetation. Moose activity in particular appears to be abnormally high along Blackbird Creek during the spring. There are no data on possible impacts to wildlife populations due to contaminants within the AOC.
Body burdens of Wildlife	A	Bioaccumulation of contaminants in wildlife may be occurring in portions of Jackfish Bay and the Blackbird Creek system, however, there are no data on contaminant burdens in wildlife. CWS plans a survey of gull populations for completion in 1993.

Table E (Cont'd)

GLWQA Impairment of Beneficial Use	Status of Impairment	Conditions In Jackfish Bay
Fish Tumours and Other Deformities	I	Although incidences of external fish tumours or other deformities have not been reported, white suckers collected from Jackfish Bay in the summer of 1988, prior to secondary treatment, had an abnormal incidence of liver neoplasms (cancers). Also, greater than 20 percent of lake whitefish had unexplainable external lesions which may be associated with pollutants contributed from mill effluent. A study of tumours in white suckers was conducted by OMOE in 1988 and results are pending.
Bird and Animal Deformities or Reproductive Problems	A	Incidents of bird or animal deformities have not been reported in the AOC. However, indications of reproductive dysfunction in white sucker, longnose sucker and lake whitefish populations in the Jackfish Bay AOC have been reported. CWS plans a survey of gull populations for completion in 1993.
Degradation of Benthos Dynamics of Benthic Populations	I	The benthic fauna have been impacted in Moberly, Jackfish and Tunnel Bays as shown by the presence of impaired communities which have increased in number and extent between 1969 and 1987. During this period, pollution intolerant species (<u>Pontoporea hoyi</u>) have decreased in density and extent whereas pollution tolerant species (tubificids) have increased in density and extent. Sediments in Moberly Lake are acutely toxic to benthic fauna.
Body burdens of Benthic Organisms	I	Opposum shrimp (<u>Mysis relicta</u>) and introduced caged mussels (<u>Elliptio complanata</u>) collected in Moberly Bay had a dioxin and furan congener pattern similar to that of the mill effluent. 2,3,7,8-tetrachlorodibenzofuran was the dominant isomer in the shrimp with traces of other congeners including 2,3,7,8-tetrachlorodibenzo-p-dioxin.
Restrictions on Dredging Activities	I	Sediments in the Jackfish Bay AOC, particularly within Moberly and Jackfish Bays contain concentrations of several contaminants which exceeded OMOE Open Water Dredged Material Disposal Guidelines and/or Provincial Sediment Quality Guidelines as of 1987/88. These include oil and grease, total organic carbon, TKN (1990), total phosphorus, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, hexachlorobenzene and total PCBs.
Eutrophication or Undesirable Algae	NI	No nuisance algal growths have not been reported.

Table E (Cont'd)

GLWQA Impairment of Beneficial Use	Status of Impairment	Conditions In Jackfish Bay
Restrictions on Drinking Water Consumption or Taste and Odour Problems Consumption, Taste and Odour Problems	NI	Drinking water for the Town of Terrace Bay is obtained from Lake Superior west of Jackfish Bay. There have been no consumption restrictions or reported taste and odour problems for treated drinking water. However, cottages are located in the old community of Jackfish, on Jackfish Bay. On occasion, the effluent drifts in this direction, making nontreated water unsuitable for consumption.
Beach Closings	NI	Bacterial densities have periodically been elevated in the vicinity of the Terrace Bay Beach as a result of the mill discharge, however, this condition has not led to beach closings. There are no other public beaches within the Jackfish Bay AOC.
Degradation of Aesthetics	I	Conditions have improved since the early 1970s, however, concerns continue to be expressed regarding the presence of foam and dark colour in Blackbird Creek and Moberly Bay.
Added Cost to Agriculture and Industry	NI	There are no agricultural or industrial activities which utilize water from the Jackfish Bay AOC.
Degradation of Phytoplankton and Zooplankton Populations	NI	There are no widespread effects within the AOC although community structures are likely altered in the immediate area of the discharge. No detailed information exists.
Loss of Fish and Wildlife Habitat	I	Major lake trout spawning grounds were located in Moberly Bay and along the shore of Lake Superior adjacent to Jackfish Bay and were impaired due to physical alteration (deposition of organic matter) and chemical contamination of sediments. Lake whitefish spawning grounds were identified along Lake Superior's shore immediately east and west of Jackfish Bay. The quality and use of these shoals has not been assessed. Blackbird Creek was noted as a brook trout stream prior to the start-up of the mill in 1948.

8.3b Body Burdens of Fish

Lake trout collected in 1989 had low concentrations of mercury, hexachlorobenzene, p,p-DDE, α-BHC, τ-BHC, α-chlordane, τ-hlordane, p,p-DDD, toxaphene, 2,3,7,8-TCDD (0.0000029-0.0000113 μg/g) and 2,3,7,8-TCDF (0.000020-0.000058 μg/g). White suckers collected during 1988 also had low concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF. The GLWQA Specific Objective for the protection of piscivorous wildlife was exceeded by maximum concentrations of total PCBs (0.44 μg/g).

8.3c Dynamics of Wildlife Populations

Blackbird Creek may attract wildlife during the spring months as the moderating influence of warm creek water tends to accelerate greening of creek side vegetation. Moose activity in particular appears to be high along Blackbird Creek during the spring. There are no data on possible impacts to wildlife populations due to contaminants within the AOC.

8.3d Body Burdens of Wildlife

Bioaccumulation of contaminants in wildlife may be occurring in portions of Jackfish Bay and the Blackbird Creek system, but, there are no data on contaminant burdens in wildlife. CWS plans a survey of gull populations for completion in 1993.

8.4 Fish Tumours or Other Deformities

Incidents of external fish tumours or other deformities have not been reported. However, the induction of MFO activity in white suckers collected from Jackfish Bay in the summer of 1988, prior to secondary treatment, was correlated with an "abnormal incidence of liver neoplasms (cancers)". Also, greater than 20 percent of lake whitefish caught in Jackfish Bay during August 1989 and August/September 1990 had unexplainable external lesions which did not appear to be related to predatory attack or infection. The presence of these lesions in an isolated, unpopulated bay which has received large volumes of pulp mill effluent, as well as the absence of reports of similar wounding in other lake whitefish, suggested to the author that there may be an association between the lesions and the discharge of bleached kraft mill effluent.

Research is continuing on the sublethal effects of mill effluent on fish, as well as the cause of the skin lesions on lake whitefish. A study of tumours in white suckers was undertaken in 1988 by the Water Resources Branch of OMOE. Results are pending.

8.5 Bird or Animal Deformities or Reproduction Problems

Bird or animal deformities have not been found in the Jackfish Bay AOC, nor have reproduction problems been specifically reported. However, reproductive dysfunction in white sucker, longnose sucker and lake whitefish populations in the Jackfish Bay AOC have been reported. Results from research into the sublethal effects of the pulp mill effluent indicated that these fish grow more slowly than reference fish, have smaller gonads, lower fecundity with age, an absence of secondary sex characteristics in males, failure of females to show an increase in egg size with age, reduced serum estradiol and testosterone concentrations, and greater hepatic mixed-function oxidase (MFO) activity.

A study to determine whether or not herring gulls in the Jackfish Bay AOC have deformities or experience reproductive problems is currently underway by the Canadian Wildlife Service. Results from this study will need to be evaluated when available (1993).

8.6a Dynamics of Benthic Populations

Between 1969 and 1987, maximum densities of pollution tolerant organisms (tubificids) increased by more than six times while densities of pollution intolerant organisms (*Pontoporeia hoyi*) decreased dramatically. During this period the extent of tubificids also increased in concert with a decrease in the extent of *P. hoyi*. Whereas in 1969 only the central portion of Moberly Bay and the northwestern portions of Jackfish Bay were affected, by 1987 the density of *P. hoyi* had decreased in Tunnel Bay as well as the eastern and central portions of Jackfish Bay.

The extent of communities identified as impaired also increased between 1969 and 1975. Between 1975 and 1987 the extent increased further and an additional impaired community was identified. Impaired communities were found to occur in sediments which had the highest mean concentrations of cadmium, copper, lead, zinc and TKN as well as high levels of fibre (loss on ignition). The impact to benthic macroinvertebrates in the Jackfish Bay AOC have been attributed to the Kimberly-Clark mill effluent.

Although there have been no benthic surveys of Blackbird Creek, the toxicity of sediments in Moberly Lake indicates that the sediment is acutely lethal to certain benthic species and is likely severely impaired.

8.6b Body Burdens of Benthic Organisms

The body burdens of native benthos (*Mysis relicta*) and introduced mussels (*Elliptio complanata*) from Jackfish Bay indicate a pattern of dioxin and furan bioaccumulation which suggests the mill effluent as the major source. This includes the bioaccumulation of tetrachlorodibenzo-p-dioxins and tetrachlorodibenzofurans. Concentrations of the highly toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin congener in *M. relicta* were 0.000009 $\mu g/g$. Concentrations of tetrachlorodibenzofurans ranged from 0.000034 $\mu g/g$ in introduced mussels to 0.000048 $\mu g/g$ in *M. relicta*.

8.7 Restrictions on Dredging Activities

Dredging operations have not been undertaken in the Jackfish Bay AOC. However, the sediments of Jackfish Bay, especially Moberly Bay, contain levels of oil and grease, total organic carbon, total phosphorus, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, hexachlorobenzene and total PCBs which exceeded the OMOE Open Water Dredged Material Disposal Guidelines and/or the Provincial Sediment Quality Guidelines Lowest Effect Levels in 1987/88. TKN measured in Moberly Lake sediments during 1990 also exceeded the PSQG Lowest Effect Level.

8.8 Eutrophication or Undesirable Algae

There are no records or observations of nuisance algal growths in Jackfish Bay.

8.9 Consumption, Taste and Odour Problems

The Town of Terrace Bay acquires its drinking water from Pumphouse Bay on the north shore of Lake Superior. There have been no consumption restrictions, or taste and odour problems reported with the treated drinking water. Cottages are located in the old community of Jackfish, on Jackfish Bay. On occasion, the effluent plume drifts in this direction, making nontreated water unsuitable for consumption.

8.10 Beach Closings

Bacteria levels have periodically been elevated in the vicinity of the Terrace Bay beach as a result of the mill discharge, but, this condition has not resulted in beach closings. There are no other public beaches within the Jackfish Bay AOC. However, exceedences of the fecal and total coliform PWQO have occurred as recently as 1987/88 and the IJC recommended guidelines for *Pseudomonas aeruginosa* and *Escherichia coli* were exceeded within Moberly and Jackfish Bays.

8.11 Degradation of Aesthetics

Mill effluent flow in Blackbird Creek and into Jackfish Bay has deteriorated the aesthetic value of the entire system. Re-routing the effluent away from the highway during the early 1970s has improved the situation but concerns are still expressed. Although the area's scenic beauty, sheltered waters and the wreck of the Rappahanock represent an attraction for boaters and divers, the area receives limited recreational use due to the mill discharge and, to a lesser extent, limited access.

8.12 Added Cost to Agriculture or Industry

When additional costs are required to treat water prior to use for agricultural or industrial purposes, this use category is considered to be impaired. There are no agricultural or industrial activities which utilize water from the Jackfish Bay AOC.

8.13 Degradation of Phytoplankton and Zooplankton Populations

There are no widespread effects within the AOC although community structures are likely altered in the immediate vicinity of the discharge. No detailed information exists.

8.14 Loss of Fish and Wildlife Habitat

Fish habitat in Jackfish Bay has not been fully described or mapped, nor has the relationship of various habitat types to fish production been evaluated. However, it is known that industrial pollutants have destroyed or significantly altered fisheries habitat in portions of Jackfish Bay.

Blackbird Creek no longer provides suitable habitat for most aquatic life and may affect the surrounding terrestrial habitat. The mill discharge into Jackfish Bay has degraded bottom sediments, fish habitat and potential spawning grounds. Organic sludge deposits cover most of the natural sediments in Moberly Bay. There are no data regarding the possible loss of wildlife habitat, particularly along the Blackbird Creek System.

1.0 INTRODUCTION

1.0 INTRODUCTION

The International Joint Commission (IJC) was established by Canada and the United States under the authority of the Boundary Waters Treaty of 1909. Responsibilities of the IJC included collecting, analyzing and disseminating data as well as making specific recommendations to the Canadian and U.S. governments regarding water quality problems in the boundary waters.

Since 1973 the Water Quality Board of the International Joint Commission (IJC) has identified specific areas in the Great Lakes Basin where serious water quality problems occurred. Originally referred to as 'Problem Areas', they were renamed 'Areas of Concern' (AOC) in 1981. The name change reflected a broader approach based on environmental quality considerations of the entire aquatic ecosystem (sediment, biota and water) rather than just water quality issues. The IJC, in conjunction with the Canadian and U.S. federal, provincial and state governments, has identified 43 Areas of Concern (AOCs) in the Great Lakes Basin of which 17 Canadian and Binational AOCs occur in Ontario.

An Area of Concern is a "geographic area that fails to meet the General or Specific Objectives of the Great Lakes Water Quality Agreement between Canada and the U.S., where such failure has caused or is likely to cause impairment of beneficial use or of the area's ability to support aquatic life" (*Annex 2, Great Lakes Water Quality Agreement of 1978*, revised 1987). Fourteen use impairments are listed in the GLWQA and the existence of any one is sufficient to list an area as an AOC. The fourteen impaired use categories are:

(i) restrictions on fish and wildlife populations;
(ii) tainting of fish and wildlife flavour;
(iii) degradation of fish and wildlife populations;
(iv) fish tumours or other deformities;
(v) bird or animal deformities or reproductive problems;
(vi) degradation of benthos;
(vii) restrictions on dredging activities;
(viii) eutrophication or undesirable algae;
(ix) restrictions on drinking water consumption or taste and odour problems;
(x) beach closings;
(xi) degradation of aesthetics;
(xii) added costs to agriculture or industry;
(xiii) degradation of phytoplankton and zooplankton populations; and
(xiv) loss of fish and wildlife habitat.

The revised *Great Lakes Water Quality Agreement of 1978* calls for the development of Remedial Action Plans (RAPs) for all AOCs. These RAPs are to take an ecosystem approach to restoring and protecting beneficial uses in AOCs. Through amendments to the *Canada-Ontario Agreement Respecting Great Lakes Water Quality*, effective April 1, 1985, Canada and Ontario agreed to identify, assess and report AOCs to the International Joint Commission, and to develop and implement RAPs for each AOC. Jackfish Bay was originally listed as an AOC based on problems related to conventional pollutants, heavy metals, toxic organics, contaminated sediments, fish consumption advisories and impacted biota due to industrial point sources (pulp mill) and in-place pollutants (contaminated sediments).

Moberly Bay, the western arm of Jackfish Bay, receives drainage from Blackbird Creek which conveys wastewater discharges from the Kimberly-Clark Canada Inc. pulp mill located in the Town of Terrace Bay (Figure 1.1). The discharge of effluent from the mill to Blackbird Creek has occurred since the mill's inception in 1948. These discharges have resulted in discoloured and malodorous water, high bacteria levels, fish and sediments contaminated with toxic compounds, and areas not capable of supporting aquatic life.

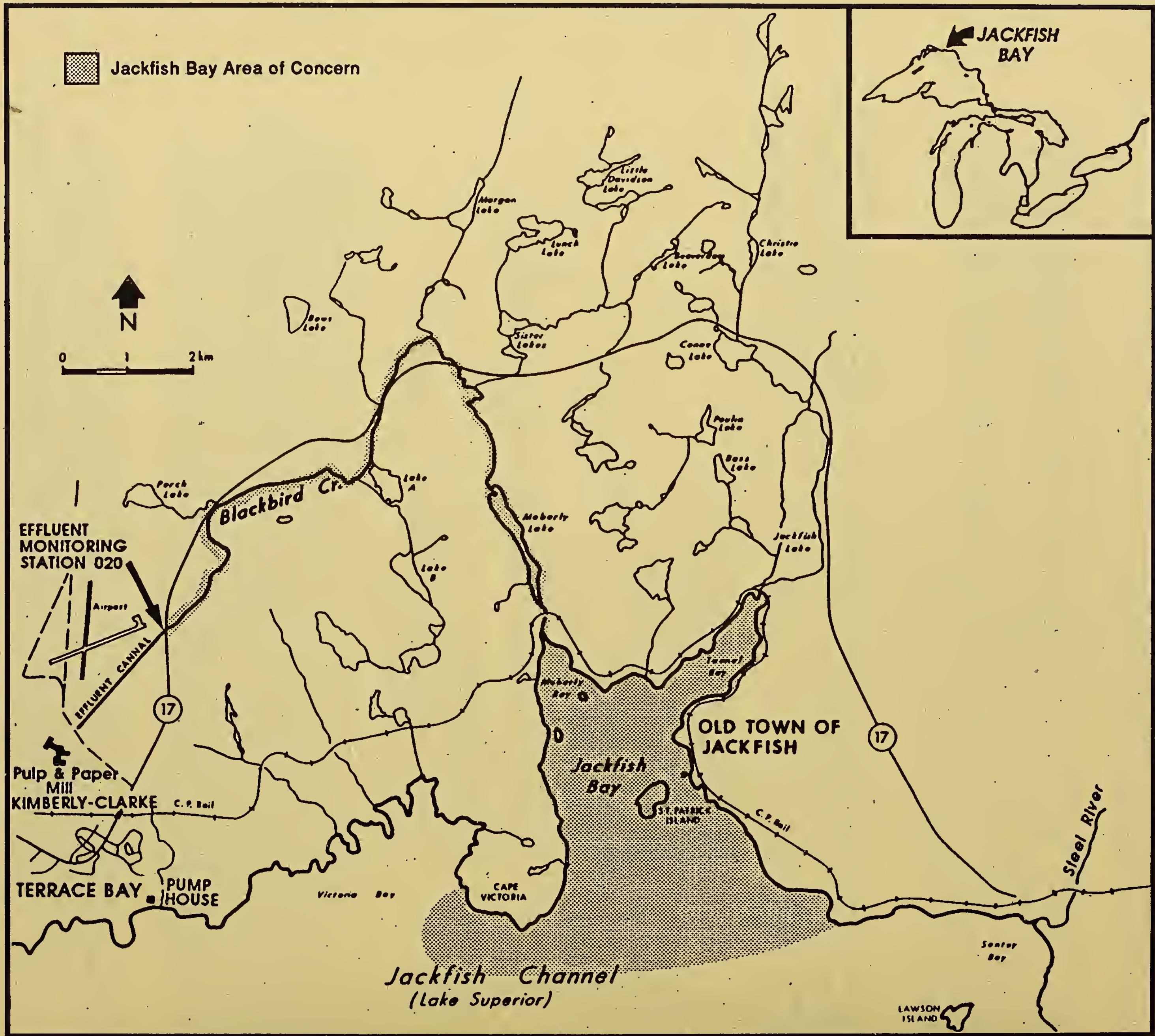


Figure 1.1

The Jackfish Bay AOC and vicinity (Sherman 1991)

The initial belief that the creek system could provide "treatment" of the mill effluent prior to its entry into Lake Superior has proven false. Low flow rates in the creek and the accumulation of solids has prevented waste assimilation. The effluent discharged through the creek system has severely impacted two lakes (Lake "A" and Moberly Lake, Figure 1.1), as well as Blackbird Creek and Moberly Bay. Although the quality of the mill effluent has significantly improved due to enhanced treatment methods, the aquatic ecosystem of the Blackbird Creek/Moberly Bay System continues to be impacted.

This report comprises Stage 1 of the Remedial Action Plan for Jackfish Bay describing environmental conditions and problems in the Area of Concern. Specific information included within the Stage 1 RAP includes (1) a definition and detailed description of the environmental problem in the AOC, including a definition of the beneficial uses that are impaired, the degree of impairment and the geographical extent of the impairment; and (ii) a definition of the causes of the use impairment, including a description of all known point and nonpoint sources of pollutants involved and an evaluation of other possible sources.

Stage 2 will define the specific goals for the AOC and describe the remedial and regulatory measures selected to meet those goals. Included in Stage 2 will be an evaluation of existing and alternative remedial measures; a schedule for implementation of the recommended remedial measures; and the identification of persons, agencies or organizations responsible for implementation.

Stage 3 is to be submitted following the restoration of beneficial uses and will include a process for evaluating the implementation and effectiveness of remedial measures; as well as a description of surveillance and monitoring processes to track the effectiveness of remedial measures and the eventual confirmation of the restoration of uses.

2.0 DESCRIPTION OF THE STUDY AREA

2.0 DESCRIPTION OF THE STUDY AREA

2.1 LOCATION AND EXTENT

The Jackfish Bay AOC is located on the north shore of Lake Superior, approximately 250 km northeast of Thunder Bay. The AOC consists of the 14 km reach of Blackbird Creek between the Kimberly-Clark mill and Jackfish Bay including Lake 'A' and Moberly Lake as well as Jackfish Bay (Figure 1.1). The Town of Terrace Bay is the closest community to the Jackfish Bay AOC. It has a population of approximately 2,700 and lies to the west of Jackfish Bay outside of the AOC.

Blackbird Creek carries the wastewater discharge from Kimberly-Clark Canada Inc. The Blackbird Creek watershed drains an area of 62 km^2 of rough, wooded terrain, swamps and several small lakes. The creek rises near the town of Terrace Bay (elevation 274 m) and flows in a south-easterly direction for approximately 14 km into the northern tip of Moberly Bay (elevation 183 m). The mean natural flow of Blackbird Creek has been estimated to be 0.7 m^3/sec (24 ft^3/sec) (German and Pugh, 1969). Historically, Blackbird Creek passed through two shallow lakes referred to as Lake 'A' and Moberly Lake. Lake A originally covered a surface area of 19 ha (47 acres) with depths ranging up to 6.1 m. Moberly Lake was 28 ha (69 acres) in size with a maximum depth of 6.4 m. Lake A was bypassed in the early 1980s because wood fibre had substantially filled it in. Moberly Lake was 0.8 m deep (as of 1982) and has also experienced significant in-filling.

Blackbird Creek was not visible from public lands until 1957, when Highway 17 was constructed east of Terrace Bay and a portion of the creek was re-routed alongside the highway. The creek was routed away from the highway in 1987.

Jackfish Bay contains two inner arms, Moberly Bay on the west into which Blackbird Creek drains and Tunnel Bay on the east (Figure 1.1). A man-made tunnel connects Jackfish Lake with Tunnel Bay. Jackfish Lake receives runoff from a small drainage basin which extends to the north of the lake. The total surface area of Jackfish Bay is 6.4 km^2. It measures approximately 4.5 km in length from north to south and approximately 3.0 km in width from east to west. There are several islands and shoals of varying size within Jackfish Bay. The largest islands are Cody Island, which is located in the extreme southwest of Moberly Bay; Bennett Island, located in southeastern Moberly Bay; and St. Patrick Island, which is located near the eastern shore of Jackfish Bay.

2.2 CLIMATIC CONDITIONS

Terrace Bay is located in the Superior Climatic Region, which is the more southerly of two climatic regions found in the Terrace Bay District (Ontario Ministry of Natural Resources, 1980). It is characterized by a moderate climate with cooler summers and milder winters than the Height of Land Climatic Region which lies to the north of the AOC. Mean daily temperatures in the Superior Region are -13.3 °C in January and 15 °C in July. Mean daily maxima and minima are -7.8 °C and -18.9 °C in January and 21.1 °C and 10.0 °C in July. Recorded mean annual rainfall is 787.4 mm with a mean annual snowfall of 243.8 cm. Precipitation is relatively low in winter and high in summer. Winter brings cold polar air masses resulting in dry, clear weather much of the time. In summer, warm, humid air masses from the south alternate with cool dry air from the north.

The north shore of Lake Superior, in the vicinity of Jackfish Bay, begins to freeze in mid January with a median ice cover (based on the 1972 to 1985 period of record) of ten to sixty percent occurring from January 12 to 18, from 70 to 90 percent from January 26 through March 15 and becoming ice free by April 6 (Minister of Supply and Services Canada 1986). Moberly Bay is not completely ice-covered in the winter due, at least in part, to the warm effluent entering via Blackbird Creek. The exact extent of open water is

not known, but, open reaches likely extend almost as far as Cody Island before ice formation becomes more stable.

2.3 PHYSIOGRAPHY, GEOMORPHOLOGY and GEOLOGY

The Jackfish Bay AOC is a bedrock dominated area forming a portion of the north shore of Lake Superior. The area around Jackfish Bay and immediately to the north is characterized by rugged, steep hills and wide river valleys. Drainage is predominantly south and southeasterly with elevations ranging from 305 m in the upper portions of the Blackbird Creek and the Jackfish Lake drainage systems to 183 m at Lake Superior.

The area lies within the Abitibi Upland Unit of the James Physiographic Region as defined by Bostock (1972). This unit is described as having a broad rolling surface and consisting of crystalline Archean rocks of the Canadian Shield.

The Canadian Shield was glaciated at least four times during the Pleistocene Period which began more than 1 million years before present. In the study area, glaciation resulted in a glacially eroded bedrock surface which controls the local topography. Glacial deposits consist mostly of a shallow sandy till ground moraine which overlies the lower portions of bedrock outcrops (Gartner 1980). A small sandy glacial outwash deposit was formed during the final retreat stages of the Wisconsin Glacier at the head of Tunnel Bay and around the southern end of Jackfish Lake. The only other deposit in the area consists of a large glaciolacustrine delta which forms the southeast shore of Jackfish Bay and strikes inland toward the northeast (Gartner 1980). This sand and gravel deposit was formed where a glacial meltwater channel drained into Glacial Lake Algonquin which was the precursor to the present Lake Superior. Erosional shore bluffs of the former glacial lake occur at elevations well above the level of Lake Superior. These bluffs, or terraces, are also common to the west of Jackfish Bay in the vicinity of the Town of Terrace Bay.

The bedrock geology of the northern and western shores of Jackfish Bay is dominated by massive crystalline igneous rocks consisting of granodiorite to granite (Ontario Geological Survey 1991). These rocks are late to middle Archean in age or approximately 2.5 to 3.4 billion years old. They also form the substrate for most of the streams and lakes which drain into Jackfish Bay. The southeastern shore of Jackfish Bay consists of late to middle Archean mafic to intermediate metavolcanic rocks. These highly metamorphosed rocks were formed from volcanic igneous rocks such as basalts, tuffs and breccias. Minor metasedimentary rocks (metamorphosed sedimentary strata) also occur within this complex (Ontario Geological Survey 1991).

2.4 SOILS

Soils are predominantly rockland and brunisols. Rockland soils occur where there is less than 10 cm of till overlying bedrock and exposed bedrock (Ontario Institute of Pedology 1981). Areas of till thicker than 10 cm consist of Orthic Eutric Brunisols in middle and upper elevations and Gleyed Eutric Brunisols to Orthic Humic Gleysols on lower slopes. The till soils are sandy and are not particularly fertile due to low nutrient content (primarily noncalcareous) and high stone content.

Wet depressions and extremely poorly drained areas consist of organic soils including Terric (shallow) and Typic (deeper than 120 cm) Humisols or Mesisols depending on the degree of humification. Soils which have formed on the sandy outwash at the head of Tunnel Bay are predominantly Orthic Humic Gleysols in imperfectly drained areas and Orthic Eutric Brunisols on better drained positions. Soils developed on sand and gravel glaciolacustrine deposits near Terrace Bay and on southeast shore of Jackfish Bay are predominantly Eluviated Eutric Brunisols.

2.5 TERRESTRIAL VEGETATION

The Jackfish Bay AOC lies within the Superior Forest Section of the Boreal Forest Region (Rowe 1972). Forests are variable due to severe climatic conditions and rugged terrain characteristic of the area (Ontario Ministry of Natural Resources 1980). They range from mixed tree species with abundant shrub undergrowth, to single species conifer stands (Rowe 1972).

Forests of white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), white birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*) are found in valleys characterized by deep, medium textured soils (Rowe 1972). The same species, but with birch more prominent and some black spruce (*Picea mariana*), is found on the thin till slopes and tops of low hills (Rowe 1972). Jack pine (*Pinus banksiana*), white birch and poor quality black spruce, are characteristic of higher rocky elevations and coarser valley soils (Rowe 1972). Lowland areas support high quality stands of black spruce along with tamarack (*Larix laricina*) and eastern white cedar (*Thuja occidentalis*). Forests in the District of Terrace Bay have been repeatedly burned, resulting in an abundance of trembling aspen, white birch and jack pine. The rough topography and variable soils, in combination with this burning, results in small stands and a patchy appearance (Rowe 1972).

2.6 LAND USE

Land use in the vicinity of Jackfish Bay is limited, for the most part, to the pulp mill and the community of Terrace Bay. Several mining companies have operated inland within the Jackfish Bay watershed, but likely have had little impact. The Empress Mine was located approximately 9.6 km east of Terrace Bay and produced gold between 1885 and 1900, and again in 1936. The Ursa Mine was located 4.8 km north of the Empress and it too produced gold until the early 1900s (Ontario Ministry of Natural Resources 1980).

The Township of Terrace Bay was established in the late 1940s in response to the developing pulp and paper industry. The pulp mill is still the main industry and source of revenue in the area.

The watershed of the AOC consists mostly of second growth forest. The only developed areas include the Highway 17 corridor and cottages at the former townsite of Jackfish on the east side of Jackfish Bay (Figure 1.1). The cottages are accessed by gravel road from the highway. There are no commercial or industrial developments along Highway 17 in this area.

There are three waste disposal sites in the general area, however, two are outside of the AOC watershed. The Town of Terrace Bay shares a municipal landfill with the Town of Schreiber. This landfill is located about 7 km west of Terrace Bay. Kimberly-Clark Canada Inc. utilizes an industrial landfill located about one km north of the mill. The only landfill within the Jackfish Bay AOC is a small site operated by the Ontario Ministry of Natural Resources. It is located two km east of the cottage area at Jackfish and receives only domestic waste from the cottages. This site does not pose any contamination problems for the Jackfish Bay AOC.

2.7 RECREATION

One of the earliest commercial recreation centres was developed in the late 1800s at the former village of Jackfish (Figure 1.1). A hotel was constructed and the tourist trade was almost totally dependent on sport fishing. Consequently, when the lake trout populations declined in the 1940s and 1950s, tourism suffered heavily.

Recreational activity in Jackfish Bay has generally been light due to limited access and the depressed sport fishery. A number of pioneer homes in the historical town site of Jackfish have been converted into summer

cottages, the only ones located in Jackfish Bay. Cottage owners represent the largest user-group for recreational activity in the bay. Jackfish Bay has noteworthy aesthetic value, with its rugged shoreline and archaeological and historical sites.

2.8 WILDLIFE

Wildlife found in the Ministry of Natural Resources' Terrace Bay Administrative District include species well adapted to the harsh climatic conditions found there. Common species include: moose, deer, timber wolf, fox, lynx, black bear, mink, fisher, martin, muskrat, beaver, porcupine, skunk, snowshoe hare and red squirrel. Shrew, mice and vole populations are also found in the District, as well as a variety of upland game birds and songbirds (Ontario Ministry of Natural Resources 1980).

Although located within the Boreal Forest Region, Sub-arctic conditions exist in exposed locations along the shoreline as a result of the influence of Lake Superior. Herds of woodland caribou exist on the Slate Islands, on Pic Island and in Neys Provincial Park. The Slate Islands have been designated as a natural environment park, and have proven popular to tourists and naturalists due to their unique fauna.

Several animal species living in the region are considered rare, threatened or endangered. They include the eastern cougar (many unconfirmed sightings), great blue heron, bald eagle, peregrine falcon, golden eagle, osprey, as well as a variety of songbirds (Ontario Ministry of Natural Resources 1980). The eastern cougar, peregrine falcon, bald eagle and golden eagle are protected under the *Ontario Endangered Species Act* (Ontario Ministry of Natural Resources 1991). In addition, the eastern cougar and peregrine falcon are listed by the Committee on the Status of Endangered Wildlife in Canada as endangered (Burnett et al. 1989).

The Ontario Ministry of Natural Resources has developed wildlife management plans with the broad objective "to provide sustained optimum cultural, social and economic benefits to the people of Ontario" (Ontario Ministry of Natural Resources, 1980). The animals which receive the most management attention due to their importance to hunting include the moose, white-tailed deer and black bear.

2.9 AGRICULTURE

There are currently no agricultural activities in the vicinity of the Jackfish Bay AOC. There is also very little potential for agricultural development anywhere in the Terrace Bay Administrative District (Ontario Ministry of Natural Resources 1980). Thin, stony soils with low fertility, rugged terrain and cool climatic conditions are the primary limiting factors.

2.10 WATER USES

2.10.1 Water Supply

Process water for the pulp mill and domestic water for the Town of Terrace Bay is obtained from a common intake located in open Lake Superior, approximately 10 km west of Jackfish Bay (Figure 1.1). A 90 cm trunk main, extending from the pumphouse to the pulp mill, provides a 30 cm feeder line to Terrace Bay's distribution system. The combined water intake increased from 102,200 m^3/day, before the mill expansion (between 1975 and 1978), to approximately 143,850 m^3/day following the expansion of the mill. The pumphouse has the potential to supply 156,960 m^3/day from any two of three pumps. Although less than 2 percent of the total supply is used for domestic purposes, all of the water is chlorinated. Hays Lake, located northwest of the Town of Terrace Bay, provides an alternate water supply.

2.10.2 Wastewater Discharges

Process water from the Kimberly-Clark Canada Inc. pulp mill is discharged into Blackbird Creek which flows over a distance of 14 km to Moberly Bay in Jackfish Bay. During 1990 the average effluent flow from the mill was 94,000 m^3/day. The effluent treatment system and effluent quality are discussed in detail in Section 4. This represents the only point source discharge within the Jackfish Bay AOC.

Municipal wastes from the Town of Terrace Bay are treated by two systems. Domestic sewage from one subdivision is treated by a small extended aeration facility and polished through an exfiltration lagoon, while sewage from the remainder of the community is passed through two septic tanks followed by an exfiltration lagoon. Both lagoons lie adjacent to Lake Superior, immediately south of the townsite and removed from Jackfish Bay. Their is no direct discharge from the lagoons (Ontario Ministry of the Environment 1991a).

2.10.3 Fish Habitat

Water depth in Jackfish Bay generally increases abruptly from the rugged shorelines to depths of 10 to 50 m. Littoral areas are limited in extent, forming extremely narrow bands along the shoreline. As a result wetlands are not present in Jackfish Bay. Nearshore fish spawning and nursery habitat is restricted to isolated pockets, primarily located in Tunnel Bay, to the west of Cody Island around Bennett Island.

Although the maximum water depth in Jackfish Bay is approximately 50 m, the maximum depth in Moberly Bay is only 20 m (Figure 2.1). The bed of Jackfish Bay slopes more steeply along its western shore with maximum depths occurring west of St. Patrick Island.

Jackfish Lake is connected to the northern tip of Tunnel Bay by a channel approximately 15 m in length. The lake, which is 127 ha in area and has a mean depth of 6.2 m, provides spawning and nursery habitat for a number of resident warmwater species in addition to migrants from Jackfish Bay. Jackfish Bay species which spawn in Jackfish Lake or its tributaries include walleye (*Stizostedion vitreum*), northern pike (*Esox lucius*), rainbow trout (*Oncorhynchus mykiss*), pink salmon (*O. gorbuscha*) and suckers (*Catostomus* sp.).

Goodier (1981, 1982) documented historical spawning areas (i.e., prior to 1955) for the major commercial species in the Jackfish Bay area. Major lake trout (*Salvelinus namaycush*) spawning grounds were located in Moberly Bay and along the shore of Lake Superior adjacent to Jackfish Bay (Figure 2.2). Lake Whitefish (*Coregonus clupeaformis*) spawning grounds were identified along Lake Superior's shore immediately east and west of Jackfish Bay (Figure 2.3). The quality and use of these shoals has not been assessed.

Blackbird Creek was noted as a brook trout (*Salvelinus fontinalis*) stream prior to the start-up of the mill in 1948. As there are no natural barriers restricting movement of fish between the creek mouth and Highway 17 (14 km), it may be presumed that Lake A and Moberly Lake formerly provided seasonal habitat for a number of fish species resident in Blackbird Creek.

2.10.4 Commercial Fishing

Commercial fishermen first settled in Jackfish Bay during the 1870s and the commercial fishery industry was well established by the mid-1880s. Jackfish Bay was noted as an excellent port, however, fishing was never extensive in the area as the adjacent shoreline was rugged and storms could be severe. The fishery was characterized as a rowboat fishery with an annual catch of approximately 14,500 kg of lake trout and 6,000 kg of whitefish between 1895 and 1898 (Goodier 1982). Commercial fishing activity peaked during the early 1900s, when approximately 40 families were permanent residents of the former Town of Jackfish (Figure 1.1).

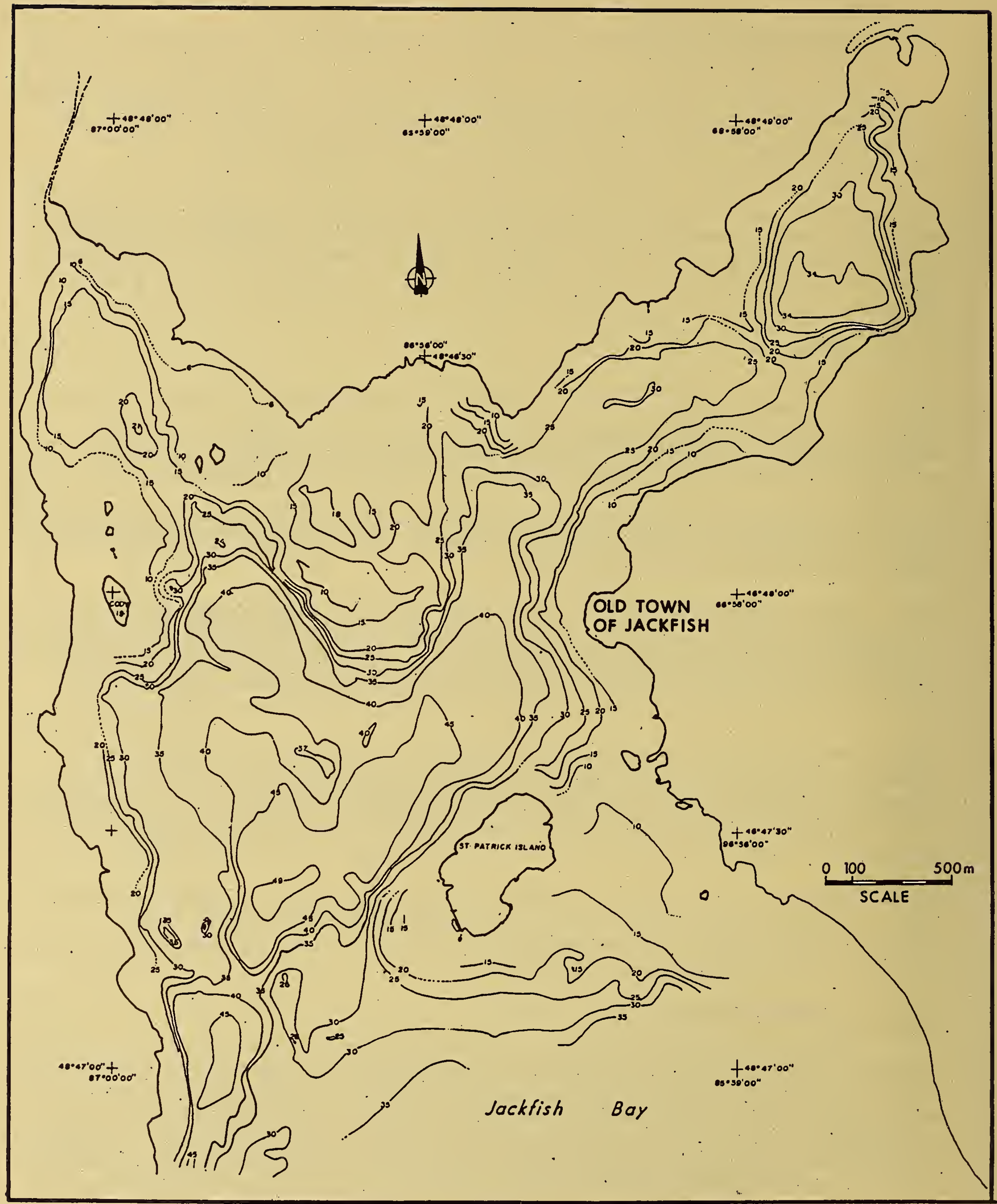


Figure 2.1

Water depth (metres) in Jackfish Bay (based on sonar survey of McQuest Marine Research Ltd., conducted October 19-30, 1987) (Sherman 1991).

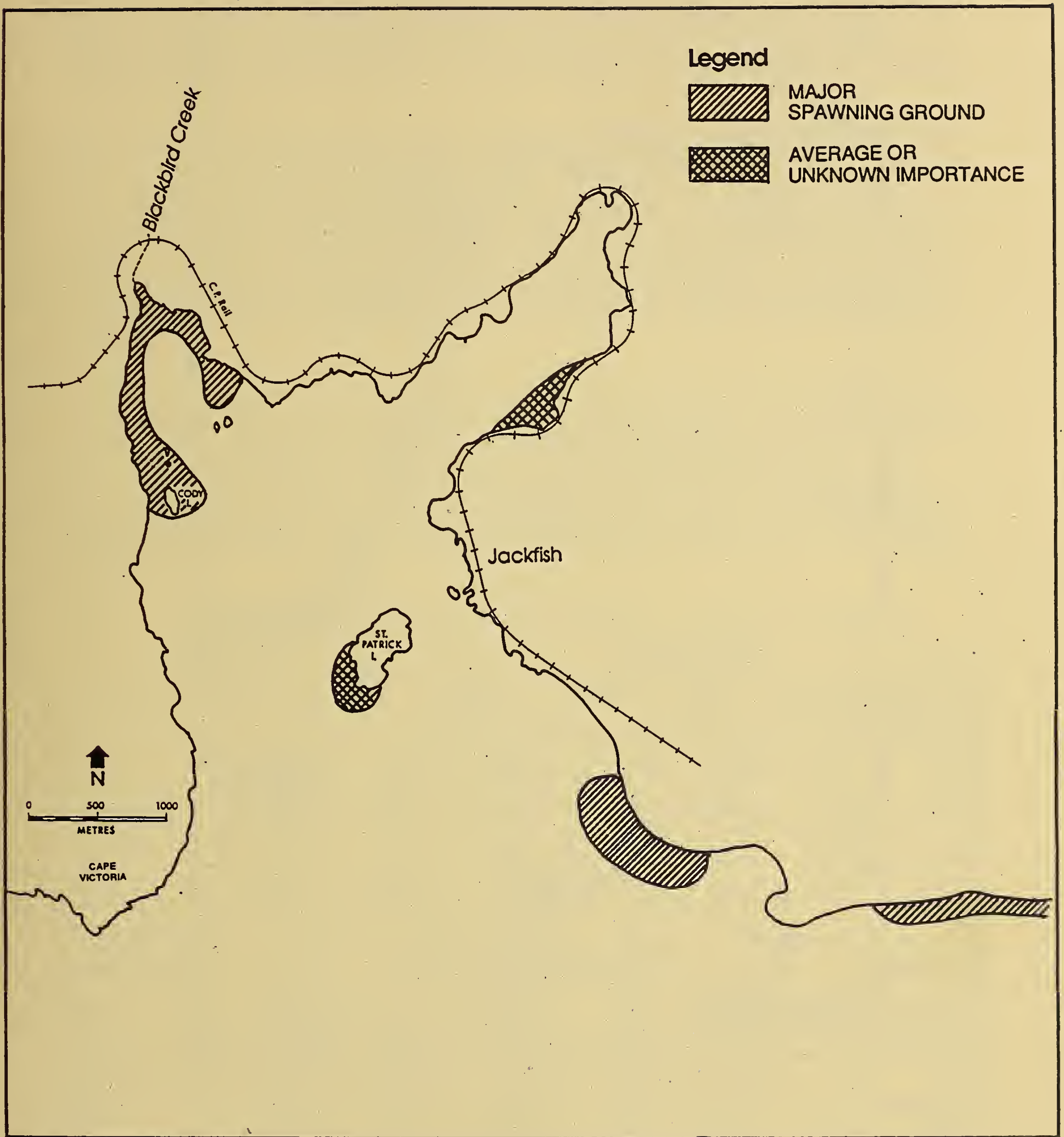


Figure 2.2

Spawning grounds for lake trout (Salvelinus namaycush) at Jackfish Bay (Goodier 1981).

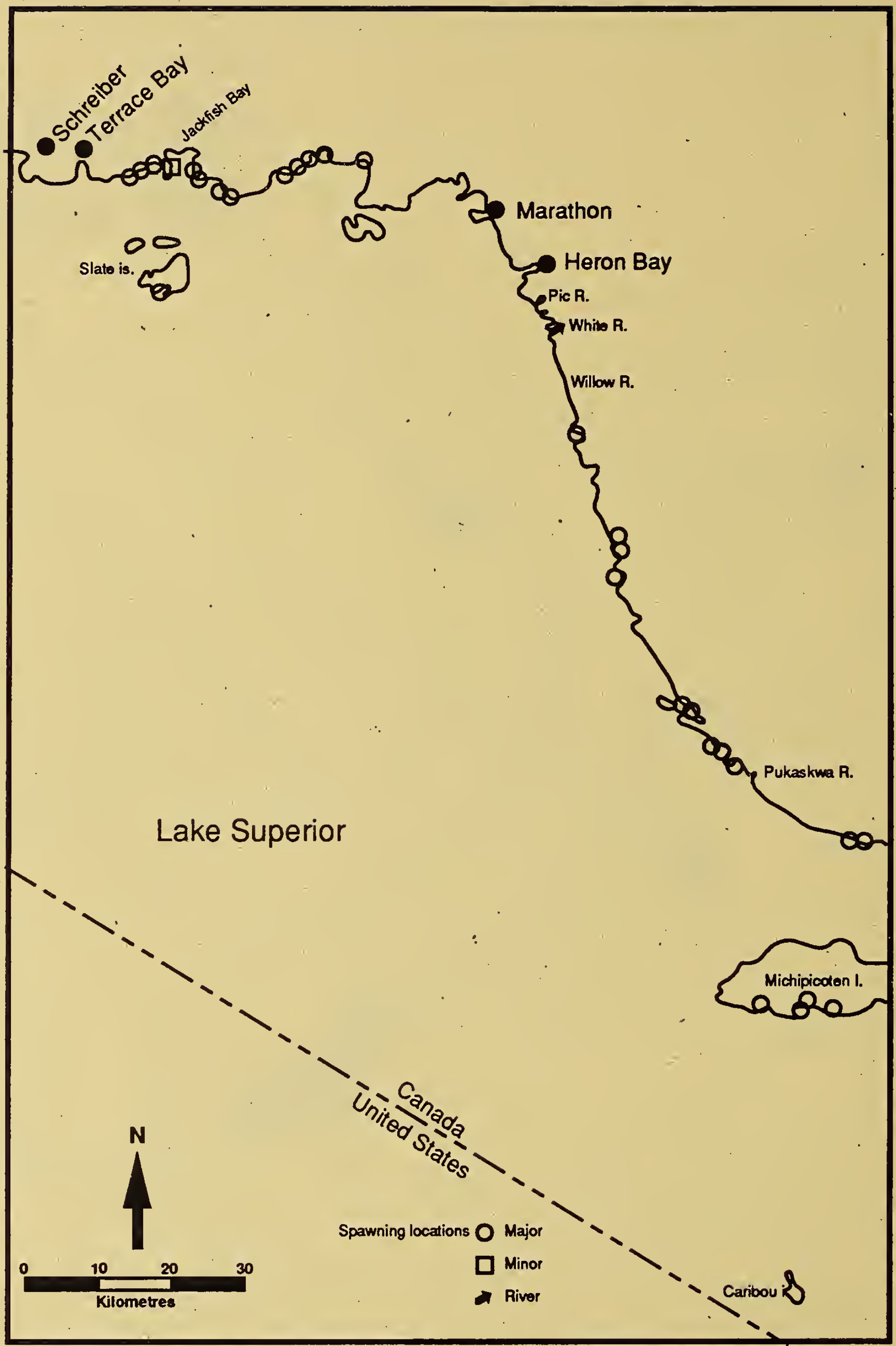


Figure 2.3

Spawning grounds of lake whitefish (Coregonus clupeaformis) Michipicoten Island to Schreiber (Goodier 1982).

The Canadian Pacific Railway converted Jackfish into a two industry town in 1884. Jackfish, due to its deep, sheltered harbour, became a transhipment point for Pennsylvania coal bound for CPR's divisional points of Chapleau and Cartier. The town continued to prosper until the late 1940s and 1950s when the CPR converted from coal to diesel. Concurrently, sea lamprey predation and heavy exploitation depleted fisheries stocks in Lake Superior.

Lakewide estimates of total harvest are available for the major commercial fish species dating back to the late 1800s (Lawrie and Rahrer 1973, Lawrie 1978). Prior to 1948, catch locations were not site specific and the commercial industry was largely unregulated. In 1948 the establishment of mandatory commercial fish harvest reporting according to defined management zones vastly improved commercial harvest statistics. Zone quotas for lake trout were first established in 1962, followed by zone quotas for all major commercial species by the mid 1970s. Individual quota management for all species was finalized in 1984. Quotas are currently set at levels designed to maintain or restore stocks while maximizing harvest. Canadian waters of Lake Superior are divided into 34 management zones. The Jackfish Bay AOC is in Zone 18 (Figure 2.4) which extends offshore into Lake Superior beyond the Slate Islands. Two commercial fishing operations are currently licensed.

The total commercial harvest in 1985 amounted to 5,082 kg (Table 2.1) which was valued at $5,727. Lake trout, lake whitefish, chub (*Coregonus* sp.) and lake herring (*Coregonus artedii*) have remained the four prime commercial species, although the order of dominance has varied since commercial fishing commenced in Zone 18. Prior to the arrival of sea lamprey in Lake Superior (early 1950s), lake trout was the major commercial species in the Jackfish Bay area. During the period from 1951 to 1953, the average annual commercial catch from Zone 18 was 56,000 kg, of which 52,500 kg were lake trout. In comparison, the lake trout commercial catch during the period 1980 through 1985 in this zone ranged between 771 and 2,307 kg (Table 2.1).

Table 2.1 Lake Superior Management Zone 18 commercial catch (round weight in kilograms) (OMNR Data Files).

Species	1980	1981	1982	1983	1984	1985	1986 Quota
L. trout	1,021	771	2,307	2,013	883	1,307	1,350
L. Whitefish	815	2,141	9,149	5,450	540	450	4,300
L. herring	35	232	180	498	59	1,167	185
Chubs	9,373	6,486	152	3,204	361	1,992	10,375
Yellow perch	0	0	0	0	0	0	0
Menominee	0	1	10	70	9	0	unlimited
Smelt	0	0	0	0	0	0	unlimited
Mullet	374	390	630	371	182	161	unlimited
Other	200	143	363	252	112	•	155
Total	11,818	10,164	12,791	11,858	2,146	5,082	163,365

Two commercial fishing licences.

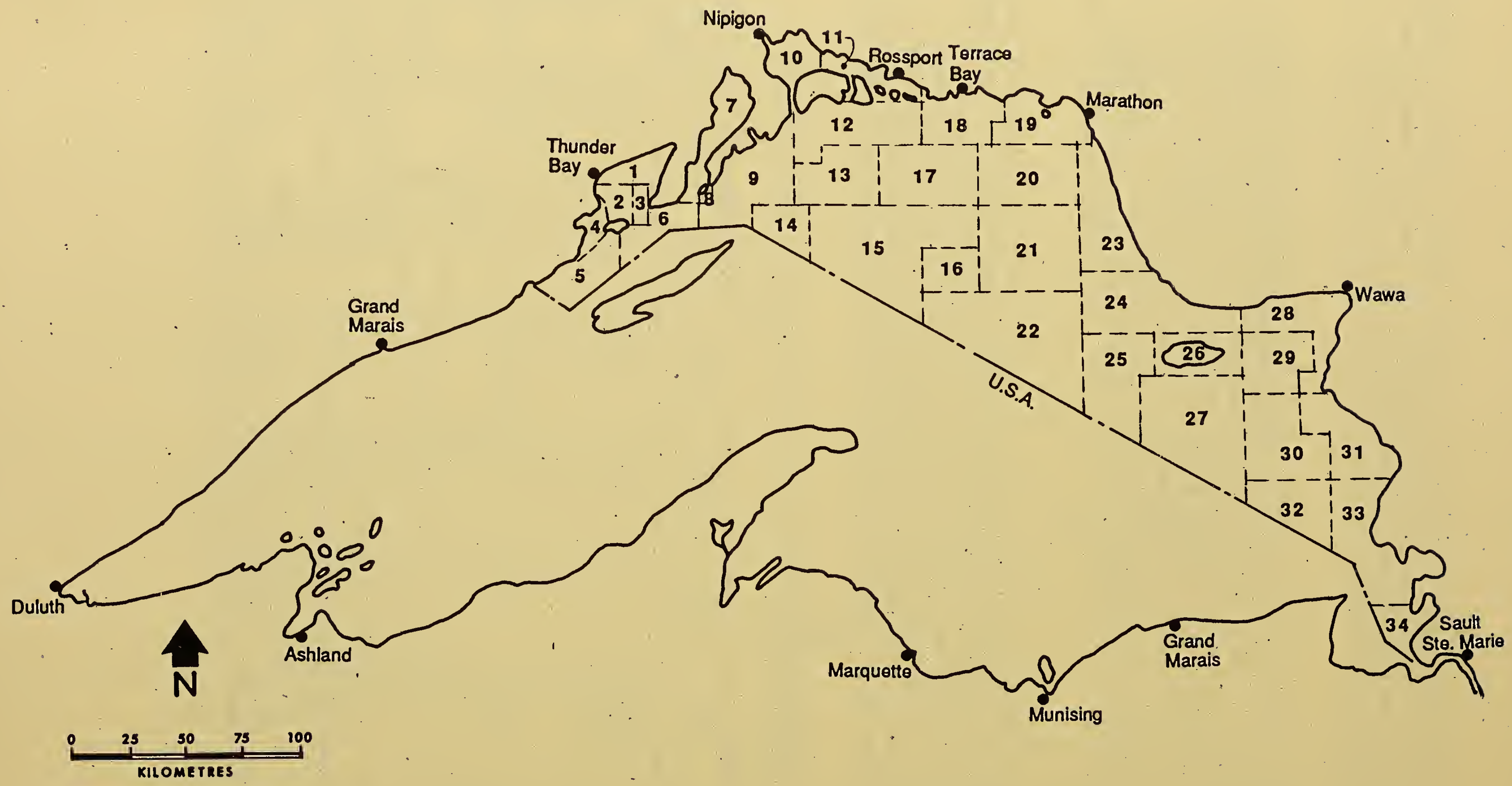


Figure 2.4

Lake Superior Management Zones (MNR data files).

Exploitation and the introduction of exotics had the greatest effect on Lake Superior's commercial fisheries prior to 1960; cultural eutrophication was not considered a major factor in the changing fisheries communities in this lake (Loftus and Regier 1972). Lake trout harvests in the Jackfish Bay area remained relatively stable prior to the sea lamprey invasion in the early 1950s. However, commercial fishing in Jackfish Bay was terminated in 1948 when Kimberly-Clark began discharging wastewater into Moberly Bay. Jackfish Bay remained a fishing port until the early 1960s, at which time commercial fishing in Zone 18 was greatly reduced. The current fishery is predominantly an offshore fishery, as nearshore lake trout stocks have not recovered to substantial levels.

The Slate Islands native lake trout stock is one of the few stocks of 'lean' trout that has persisted in Lake Superior. It is one of two lake trout stocks identified in Ontario as sources for Lake Superior hatchery broodstocks. In 1969 the Ontario Ministry of Natural Resources imposed a one mile closure to commercial fishing surrounding the Slate Islands. These islands lie approximately 14 km south of Jackfish Bay. Lake trout stocking in Zone 18 was intermittent prior to 1983, totalling 50,292 yearlings/fingerlings from 1970 to 1982. Stocking rates, however, averaged 55,000 fish per year from 1983 to 1987. Zone 18 has been assigned "first priority for stocking" under the auspices of the 1986 Lake Trout Rehabilitation Plan for Lake Superior. Accordingly, stocking will continue at the present rate for a minimum of five years. Lake trout, the only species stocked in Zone 18, have never been introduced directly into Jackfish Bay.

2.10.5 Sport Fishing

Sport fishing in Jackfish Bay declined dramatically during the 1950s and has remained depressed under current conditions. Lake trout spawning shoals appear to have been adversely affected by organic material in the discharge from the Kimberly-Clark mill. Electrofishing surveys found few species and low numbers of fish in Moberly Bay as well as increasing numbers and species diversity with increasing distance from the mill outfall.

Most recreational fishing occurs offshore around the Slate Islands. Lake trout are the most abundant fish taken in the open lake while there is a limited nearshore fishery for rainbow trout and brook trout.

Rehabilitation measures, in the form of hatchery introductions and sea lamprey control, may have resulted in substantial increases in sport fishing activities during the late 1970s and the 1980s in many inshore areas of Lake Superior. Degraded water, sediment and benthic fauna and, perhaps, low stocking rates in areas adjacent to Jackfish Bay have prevented a similar trend in the AOC. Reliable estimates of sport fish harvest are not available for Jackfish Bay. Prior to the 1950s, angling was popular and Jackfish was the site of an annual fishing derby.

2.10.6 Recreation

The Jackfish Bay AOC is an attractive location for recreational use. However, Lake Superior's inherent cold water conditions, poor aesthetics related to the effluent from Blackbird Creek, and limited access restrict traditional water activities.

Water based recreational activities are restricted to minor sport fishing (Section 2.10.5) and scuba diving by local residents. The wreck of the Rappahannock, a 94 m bulk freighter which sank in 1911 in Tunnel Bay, is a popular local dive site. The only public beach in the area is the Terrace Bay Beach on the north shore of Lake Superior. It is located near the town about 10 km west of Jackfish Bay. There are no beaches within Jackfish Bay and there is no information on the use of the bay by local cottagers.

There are no boat launch sites located on Jackfish Bay. Small craft can access Lake Superior at the Aguasabon River west of Jackfish Bay and through Jackfish Lake. The CPR tunnel in the channel between Jackfish Lake and Tunnel Bay restricts the size of watercraft that can travel between the two water bodies. The launch sites offer the most direct access to the Slate Islands Provincial Park and the offshore lake trout fishery.

3.0 ENVIRONMENTAL CONDITIONS

3.0 ENVIRONMENTAL CONDITIONS

3.1 WATER QUALITY

Various agencies have developed water quality objectives based on different factors. Examples are the Provincial Water Quality Objectives (PWQOs) and the Great Lakes Water Quality Agreement (GLWQA) Specific Objectives. The PWQOs were designed for "the protection of aquatic life and recreation in and on the water" (Ontario Ministry of the Environment 1984) while the GLWQA Specific Objectives are "based on available information on cause/effect relationships between pollutants and receptors to protect the most sensitive use in all waters" (International Joint Commission 1987).

The following water quality summary for Jackfish Bay is based primarily on data collected by the Ontario Ministry of the Environment in 1970 (OMOE 1972), in 1981 (Kirby 1986) and in 1987/88 (Sherman 1991). The sample locations for each survey are provided in Figures 3.1, 3.2 and 3.3. Many of the sample locations are comparable for all three surveys, particularly the 1981 and 1987/88 surveys which utilized the same numbering system. Generally the density of sampling in Jackfish Bay and Lake Superior was highest during the 1981 surveys (Figure 3.2) and the density of sampling in Moberly and Tunnel Bays was highest in the 1987/88 surveys (800 series locations, Figure 3.2). The 1970 survey consisted of one sample collected at each station during the month of August. The 1981 surveys included 2 or 3 samples collected on consecutive days in each of June and September. The discussion of results for this survey are confined to the June samples as the mill was closed for maintenance prior to the September surveys and, hence, these surveys are not considered representative (Kirby 1986). The 1987 surveys consisted of between 2 and 6 consecutive day samples (most stations were sampled 3 times) during July and August and the 1988 surveys consisted of between 2 and 4 consecutive day samples (most sampled twice) during July. Although data from each of the surveys are provided in the text and in tables, the complete data set for each is provided in Appendix 3.1.

Data from these surveys are discussed by parameter and then compared to the PWQO and GLWQA Objectives as a means of assessing water quality in the area. Changes in water quality over the years is also discussed.

3.1.1 Currents and Plume Characteristics

In 1987, Gore and Storrie set up the Rand Model to mimic the warm buoyant effluent discharged by Kimberly-Clark Canada Inc. into Jackfish Bay (Gore and Storrie 1990). The model reproduced the hydrodynamic flow field from July 11 to August 28 and indicated that currents generally move into Jackfish Bay from the east and exit the bay out of its western edge. The model predicted that the effluent plume from Blackbird Creek would flow southward through Moberly Bay following the western edge of Jackfish Bay. These results are consistent with an earlier study (Beak Consultants 1977) which determined that water circulation is in a counter-clockwise pattern, with open lake water moving northward into Jackfish Bay along the eastern side of St. Patrick Island and the mill effluent being generally confined to the western side of the Bay.

Results from current measurements carried out for Jackfish Bay during the summer of 1984 (Beak Consultants 1984) indicated that wind direction during the study period was most commonly in the NW through SW (315° - 225°) and the SE through SW (135° - 225°) sectors (Table 3.1). These directions generally align with the longitudinal axis of Moberly Bay and Jackfish Bay; the highest current and wind speed directions were observed to also have these vectors (Beak Consultants 1984). These results suggest that wind has a great impact on local surface currents. Average current speed during the study period was only 2.0 cm/sec compared to the typical Great Lakes average of 8 - 10 cm/sec. Results from drogue tracking indicated that the surface current speed ranged from 1.5 to about 3.0 cm/sec to the northwest.

Figure 3.1

Locations of water sampling stations in Jackfish and Moberly Bays during the August 1970 water quality survey (OMOE 1972).

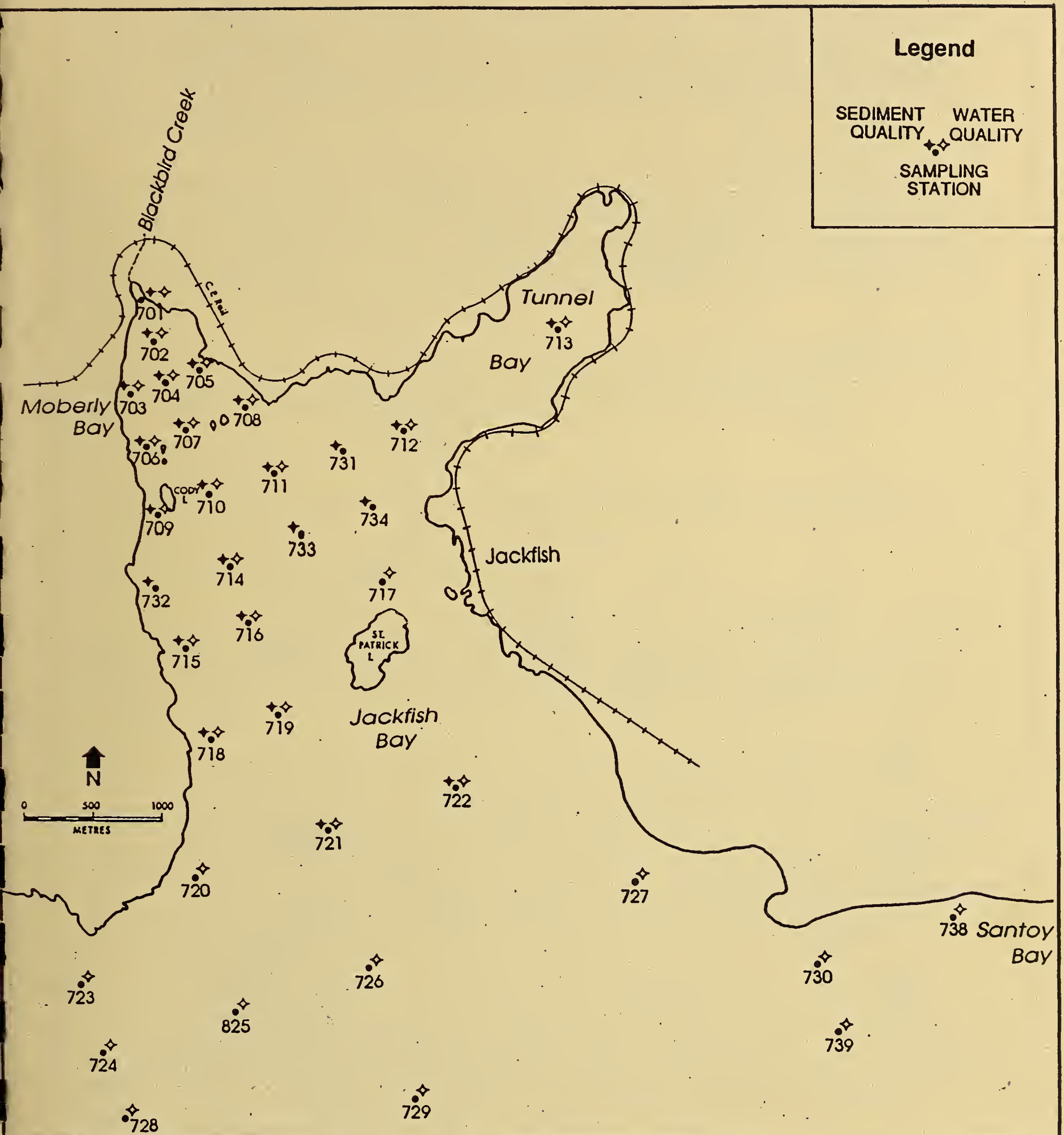


Figure 3.2

Sampling station locations for the 1981 water survey in Jackfish Bay (Kirby 1986)

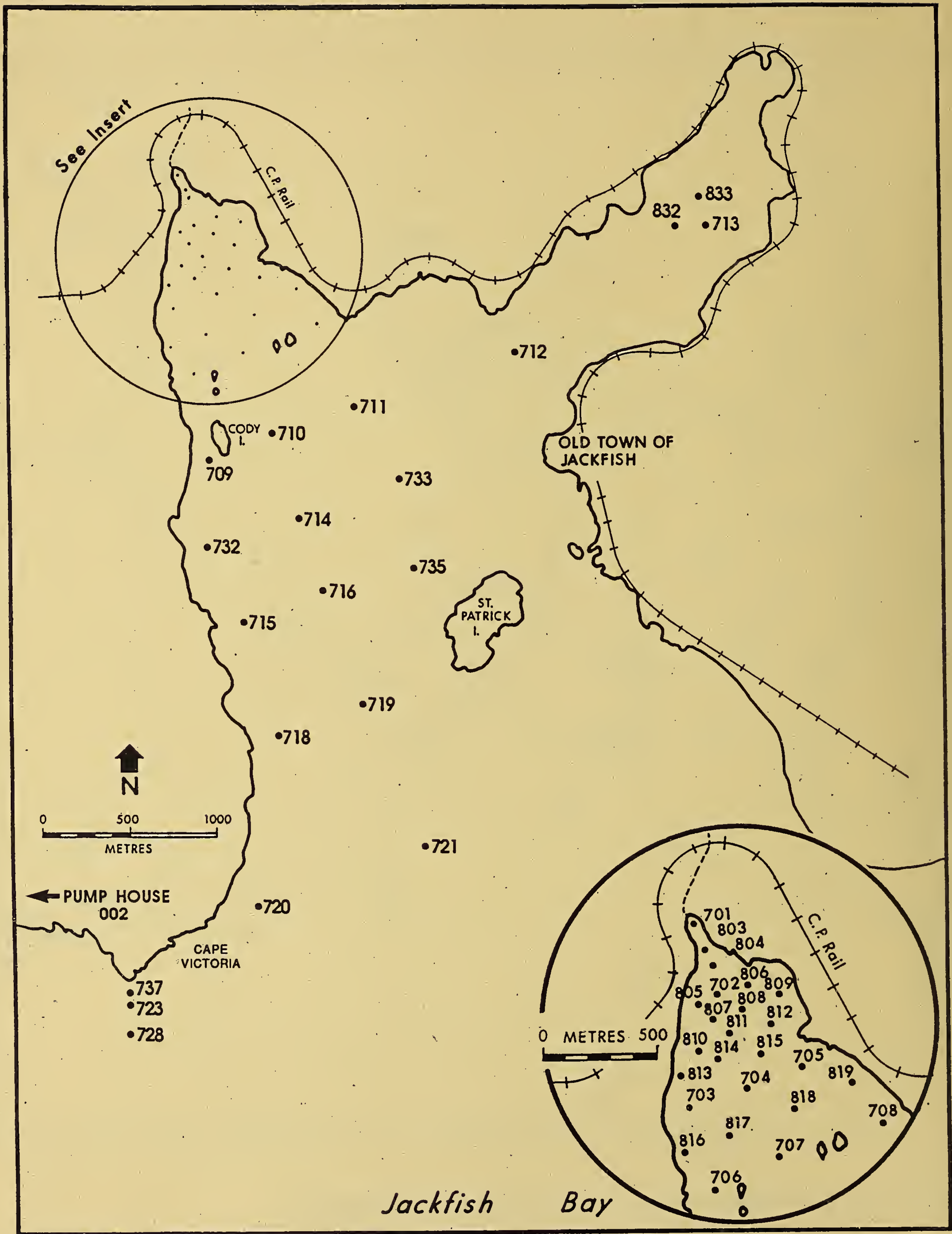


Figure 3.3

Locations of water sampling stations in Jackfish Bay for the 1987/1988 surveys (Sherman 1991).

During ice free conditions, the Blackbird Creek discharge floods the surface of Moberly Bay (Sherman 1991). The discharge generally travels south along the western shore of Moberly Bay to Cape Victoria, a distance of five km. Variable wind direction and speed can alter the shape and extent of the surface plume. Drogue tracking studies conducted during July and September of 1987 revealed a predominant southward direction in Moberly and Jackfish Bays although occasional eastward and northeast tracks toward Tunnel Bay were observed (Sherman 1991).

The strong thermal stratification or layering of the plume over the colder waters of Moberly and Jackfish Bays, results in poor effluent plume dispersion. The shape of the plume and the rate of its dilution by water in Jackfish Bay on two different days in each of July 1987 and July 1988 are illustrated in Figure 3.4. This figure is based on direct conductivity measurements and shows the rate of dilution of the plume in terms of the rate of conductivity decrease. The Blackbird Creek discharge is diluted to less than 25:1 within most of Moberly Bay and dilution to less than 100:1 often does not occur until the plume extends beyond Cape Victoria.

The effluent plume results in a gradient of warm, turbid, brown-coloured surface water having a much higher dissolved solid concentration extending from the mouth of the Creek into Jackfish Bay. As a result, water quality in Jackfish Bay is distinctly different than typical Lake Superior embayments.

3.1.2 Conventional Water Quality Parameters

Conventional water quality parameters include water colour, turbidity, temperature, dissolved oxygen and biological oxygen demand, nutrients, major ions and bacteria.

3.1.2.1 Water Colour and Aesthetics

Colour may be detrimental in that it interferes with the passage of light, thereby impeding the photosynthesis of aquatic plants. Guidelines suggest that no undue increase in the colour of natural waters be allowed through waste disposal or other activities (McNeely et al. 1979). Organic and inorganic materials contribute to the colour of water. Apparent Hazen Colour Units (HCU) are influenced by suspended matter and by dissolved constituents. There are no Provincial Water Quality Guidelines for colour in ambient waters.

Colour (HCU) was measured at one station in Blackbird Creek as well as stations in Moberly Bay (10 stations), Jackfish Bay (11 stations) and Tunnel Bay (1 station) during August 1970 (OMOE 1972). The station locations are shown in Figure 3.1. Blackbird Creek had a colour value of 1,375 HCU. Samples from Moberly Bay were >2,500 HCU at the outlet of Blackbird Creek (Station 1) decreasing rapidly to <10 HCU at the northern end of Jackfish Bay (Stations 12, 13 and 14). Stations in southern Jackfish Bay (Stations 20, 21 and 22) and in Tunnel Bay (Station 19) had an HCU value of <5. The median and range of colour values for all stations sampled in 1970 were 10.5 and 2 to 2,500 HCU, respectively (Kirby 1986). These latter stations represent close to background conditions as they are outside the main plume (Figure 3.4) and, hence, reveal a pattern of strong colour change due to effluent from the Kimberly-Clark mill.

Colour was also measured during the June and September 1981 surveys (Kirby 1986). Stations sampled during 1981 included most of stations sampled in 1970 as well as additional stations, particularly outside of Jackfish Bay in Lake Superior (Figure 3.2). In comparison to the same stations sampled in 1970, the June 1981 survey indicated little or no improvement in colour. Although the upper range of colour values was less than half that of 1970 - 921.3 as compared to 2,500 HCU in 1970 - the median value was almost seven times higher - 72.2 as compared to 10.5 HCU (Kirby 1986). The 1981 median was found to be significantly ($p < 0.05$) higher than the 1970 median value.

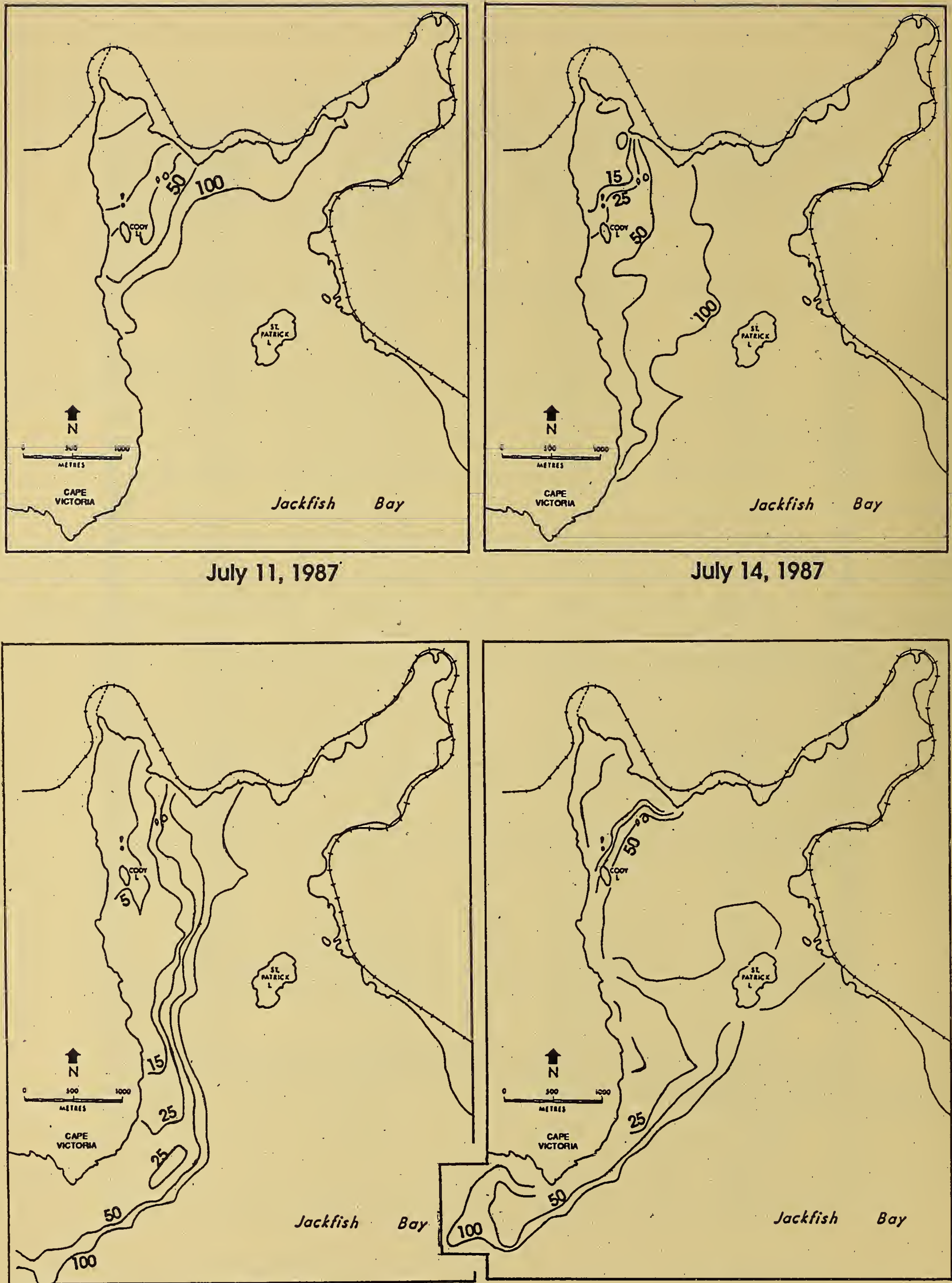
Table 3.1. Jackfish Bay measured wind speed and direction, Summer 1984 (IEC Beak, 1984).

Date	Time	Average Wind Speed	Prevailing Direction
June 1	18:00 - 24:00	11.5	180°
June 2	24 - 06	14.3	150°
	06 - 12	22.3	135°
	12 - 18	6.0	160°
	18 - 24	4.8	180°
June 3	24 - 06	5.5	180°
	06 - 12	7.8	180°
	12 - 18	6.2	180°
	18 - 24	9.0	180° - 330°
June 4	24 - 06	9.1	330°
	06 - 12	6.7	330° - 150°
	12 - 18	6.5	160°
	18 - 24	5.6	VAR
June 5	24 - 06	6.5	VAR
	06 - 12	13.5	VAR - 140°
	12 - 18	12.0	140°
	18 - 24	3.5	160°
June 6	24 - 06	4.2	VAR
	06 - 12	8.7	VAR
	12 - 18	4.8	VAR
	18 - 24	11.7	VAR - 135°
June 7	24 - 06	16.5	140°
	06 - 12	16.3	180°
	12 - 18	11.5	180°
	18 - 24	6.8	VAR
June 8	24 - 06	21.5	140°
	06 - 12	21.2	160° - 240°
	12 - 18	15.2	240° - 330°
	18 - 24	14.0	260°
June 9	24 - 06	7.7	360° - 180°
	06 - 12	13.7	180° - 040°
	12 - 18	20.3	040°
	18 - 24	28.2	030°

Table 3.1 (Cont'd)

Date	Time	Average Wind Speed	Prevailing Direction
June 10	24 - 06	23.7	010°
June 22	12 - 18	4.5	150°
	18 - 24	8	135°
June 23	24 - 06	7.2	150°
	06 - 12	12.7	130°
	12 - 18	12.2	135°
	18 - 24	8.2	165°
June 24	24 - 06	5.3	165°
	06 - 12	19.8	300°
	12 - 18	26.3	315°
	18 - 24	16.2	320°
June 25	24 - 06	7.2	320°
	06 - 12	12.3	350° - 210°
	12 - 18	22.8	210°
	18 - 24	10.3	180°
June 26	24 - 06	9.5	120°
	06 - 12	12.2	130°
	12 - 18	9.2	170°
	18 - 24	3.7	VAR
August 3	12 - 18	12.0	180°
	18 - 24	7.7	180°
August 4	24 - 06	4.0	180°
	06 - 12	6.3	190°
	12 - 18	9.7	180°
	18 - 24	3.0	195°
August 5	24 - 06	3.8	210°
	06 - 12	3.8	240°
	12 - 18	11.0	180°

Station Dismantled August 20th



July 11, 1987

July 14, 1987

July 16, 1988

July 18, 1988

Figure 3.4

Dilution of the effluent plume from Blackbird Creek based on the rate of reduction of conductivity measured in the plume in July 1987 and 1988 (unitless values) (Sherman 1991).

The results of the colour measurements from the 1988 surveys are shown in Figure 3.5. The results are comparable to that of the 1981 surveys in which the upper range of values approached 1,200 HCU. The colour value decreased gradually to between 50 and 10 near the southern portion of Moberly Bay and to background levels at the edge of the plume (1 HCU) and in southeast Jackfish Bay (Figure 3.5).

In addition to measurements of colour, the 1970 studies (OMOE 1972) also noted that degradation in the aesthetic quality due to odour, floating foam and the dark brown colour of Blackbird Creek and Moberly Bay was "perhaps the most serious impairment in terms of its effect on other water uses". The report also indicated that the offensive odour and objectionable appearance due to foam and the colour of Blackbird Creek have degraded the aesthetic value of the surrounding area as "is evident from the numerous complaints by passing motorists" (OMOE 1972). Subsequent to these studies, Kimberly-Clark installed culverts and landscaped the Highway #17 crossing of Blackbird Creek to alleviate the aesthetic impairment. It was the conclusion of the OMOE (1972) report, however, that additional work was required.

Substantial improvements were made in the Kimberly-Clark mill effluent treatment system subsequent to the 1981 surveys. However, degradation due to colour had not improved as of July of 1988.

3.1.2.2 Turbidity

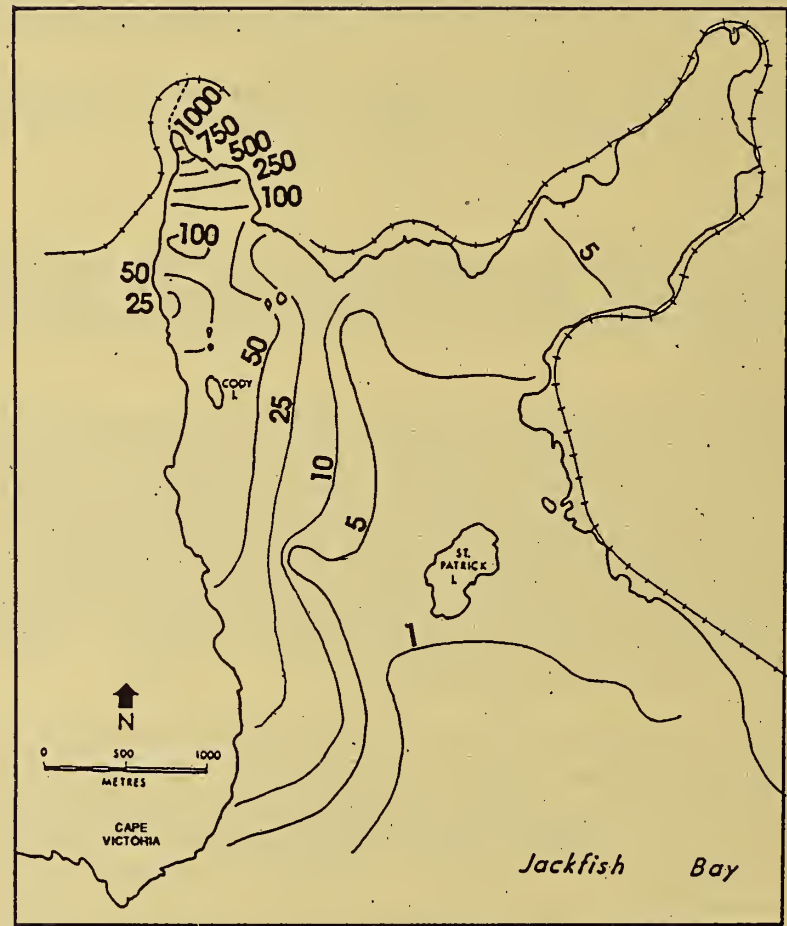
Turbidity is a measure of the suspended particles such as silt, clay, organic matter, plankton and microscopic organisms in water which are usually held in suspension by turbulent flow (McNeely 1979). The Ontario Provincial Water Quality Objective (PWQO) for ambient water turbidity requires <10 percent Secchi depth decrease (OMOE 1984).

Turbidity is a useful characteristic for assessing water quality in areas receiving industrial wastewaters such as those from pulp mills. Receiving waters may have reduced clarity due to the presence of suspended materials such as organic matter from the effluent. Water clarity affects the ability of aquatic life such as algae to thrive in the receiving waters, and may be determined by taking secchi disc readings in the field or by laboratory measurements of optical interferences to the transmission of light (JTU - Jackson Turbidity Units or FTU - Formazin Turbidity Units). Secchi disc values are obtained by determining at what depth the black and white secchi disc is no longer visible from above. Although measurements of JTU and FTU are generally similar their values can not be directly compared to secchi disc. In general, secchi disc depths should decrease as FTU/JTU measurements increase.

The results of the 1970 investigation (OMOE 1972) indicated that highest turbidity occurred in Blackbird Creek and in Moberly Bay adjacent to the outfall (Station 1, Figure 3.1 and Appendix 3.1). These were found to have turbidity values of >150 JTU. The remainder of the samples within Moberly Bay were in the range of 2.5 to 4.9 JTU. The Tunnel Bay sample (Station 19) was 1.3 JTU which corresponded approximately to the values observed at stations in southern Jackfish Bay (1.5 to 2.5 JTU).

The June 1981 median turbidity for all samples collected in Moberly, Jackfish and Tunnel Bays (Stations 701-726, Figure 3.2) was 0.6 FTU with a range of 0.15 to 3.4 FTU (Kirby 1986). The data for each station were not provided by Kirby (1986).

The results of the 1987 and 1988 surveys revealed much higher turbidity values in Moberly Bay than found in 1970 or implied by the ranges reported for 1981. Turbidity values from 1987/88 ranged from 0.20 to 460 FTU. The Moberly Bay stations recorded mean values between 0.52 and 27.30 FTU (one high mean of



July 24, 1988

Figure 3.5

Colour values (HCU) for 1988 (Sherman 1991).

154.00 FTU was recorded at Station 811) in July and August of 1987 and between 0.63 and 25.00 FTU in July of 1988. The highest mean values were observed at the stations located closest to the mouth of Blackbird Creek (Stations 701, 702, 803, and 805-810, Figure 3.3). In comparison, stations in Tunnel and Jackfish Bays had mean values of between 0.25 and 1.80 during all three sampling periods which are comparable to the values found during the 1970 survey.

The 1987/88 survey included an investigation of water clarity as determined from secchi disc measurements (Sherman 1991). Secchi disc readings indicated that water clarity was poor within both the plume and Moberly Bay with depths ranging between 0.1 and 2.5 m. Outside the plume, in Jackfish Bay and Tunnel Bay, clarity was good with values of 3.0 to 8.0 m. Poor clarity within Moberly Bay was due to a combination of high dissolved colour (Section 3.1.2.1) and high suspended solids resulting from the Blackbird Creek discharge. Spatial trends in suspended solids concentrations were similar to those of colour with the highest concentrations near Blackbird Creek at Stations 701, 803 and 806 (greater than 30 mg/L) and declined to background levels of less than 1 mg/L (Figure 3.6).

The PWQO for turbidity was exceeded within the plume, including all of Moberly Bay, during the 1987 and 1988 surveys because the secchi disc depth measurements were reduced by more than 10 percent as compared to background conditions outside the plume. In addition, there does not appear to be any improvement in turbidity within areas of the AOC affected by the effluent plume between 1970 and 1988.

3.1.2.3 Dissolved Oxygen, BOD_5 and Temperature

Dissolved oxygen levels are an important characteristic of water, as they determine the ability of fish and other oxygen-requiring aquatic life to survive. Low oxygen levels can have an adverse affect on biota which is compounded when water temperatures are high. Dissolved oxygen levels in receiving waters may be reduced due to oxygen demanding materials which are measured in effluent as Biological Oxygen Demand - 5 day (BOD_5) and Chemical Oxygen Demand (COD). The PWQO require a percent saturation of between 54 and 57 percent for water temperatures normally found in Lake Superior and its embayments. This is also expressed as a concentration of O_2 of greater than 5 mg/L for the protection of cold water biota (OMOE 1984).

Dissolved oxygen was measured as percent saturation during the 1970 survey. Although the percent saturation increased with distance from the mouth of Blackbird Creek, all stations were within the PWQO. The lowest value of 60 percent occurred at Station 1 (Figure 3.1) closest to the mouth of Blackbird Creek. This station also had the highest BOD_5 (240 mg/L). The remainder of stations in Moberly Bay ranged between 71 and 80 percent saturation whereas those in Jackfish and Tunnel Bays ranged between 75 and 96 percent (OMOE 1972). The BOD_5 concentration ranged between 1.6 and 3.9 mg/L (mean 2.34 mg/L) in Moberly Bay and between 1.2 and 1.8 mg/L (mean 1.39 mg/L) in Jackfish and Tunnel Bays.

The 1987/88 water quality survey was conducted before the secondary treatment system was brought on line by the mill, and the Blackbird Creek discharge was found to be high in oxygen demanding material. As in the case for colour and turbidity, the high biological oxygen demand of the Creek discharge extended through much of Moberly Bay (Figure 3.7) resulting in partial depletion of dissolved oxygen in the surface waters. BOD_5 concentrations in Moberly Bay were much higher at most stations during these surveys than found during 1970. Figure 3.7 shows the results for individual days in 1987 and 1988. The concentration of BOD_5 in the upper half of Moberly Bay ranged between 4 and 100 mg/L. The concentration decreased to about 1 mg/L at the southern end of Moberly Bay in July 1987 and within the central portion of Jackfish Bay in July 1988 (Figure 3.7).

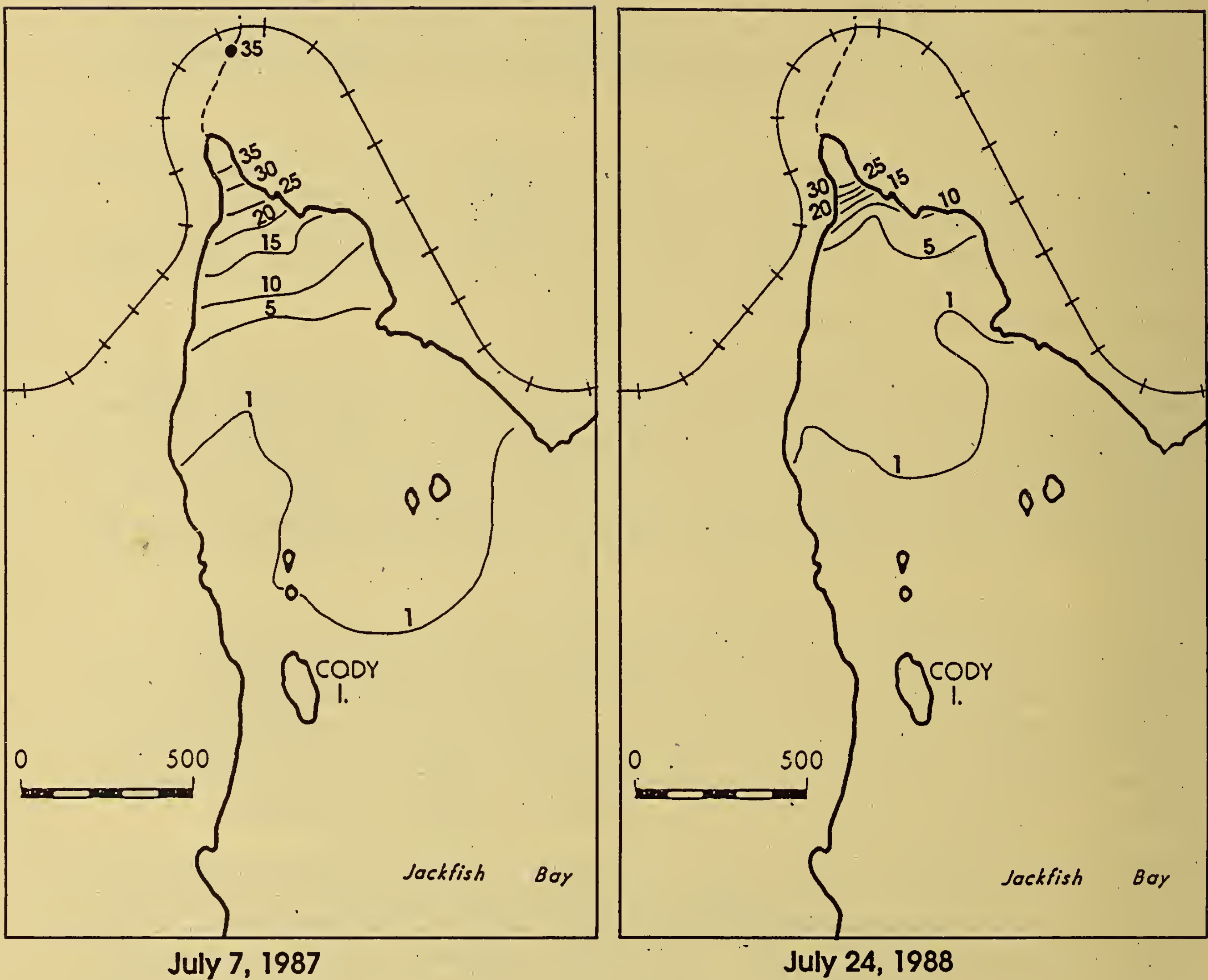


Figure 3.6

Suspended solid concentrations (mg/L) for 1987 and 1988 (Sherman 1991).

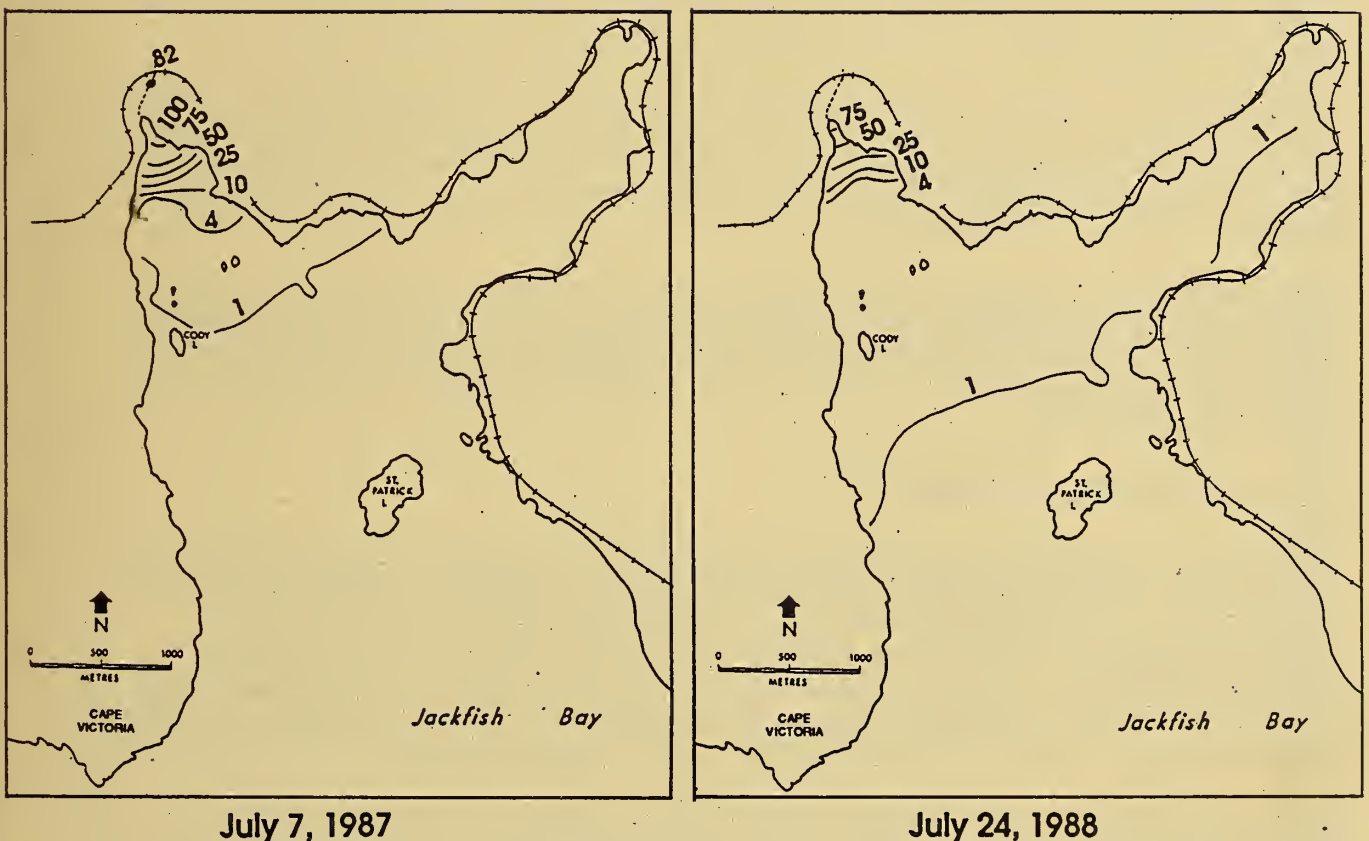


Figure 3.7

BOD concentrations (mg/L) for 1987 and 1988 (Sherman 1991).

The mean value of station means for Moberly Bay was 16.0 mg/L and for Jackfish/Tunnel Bays was 0.83 mg/L. Typical values for open water in Lake Superior embayments are less than 1 mg/L (OMOE 1983).

Figures 3.8 and 3.9 compare vertical profiles of temperature and oxygen for Station 701 in Moberly Bay, Station 716 in Jackfish Bay and Station 713 in Tunnel Bay on selected days in the summers of 1987 and 1988. Surface waters at Station 701 had much lower dissolved oxygen concentrations than Stations 713 or 716, which demonstrates the oxygen demanding nature of the mill effluent on the receiving waters. The values recorded for the samples shallower than 4 m at Station 701 were in violation of the PWQO for waters less than 20°C. Waters below the thermocline (approximately 6 to 8 m deep, Figure 3.9), which limits the depth of the plume in Moberly Bay, were similar in temperature and oxygen concentration to waters in Tunnel Bay and appeared unaffected by the effluent.

In conjunction with a fish bioassay conducted in 1983, dissolved oxygen concentrations were taken throughout Jackfish Bay (Flood et al. 1986). The lowest values detected during the study period were from sites located along the western shore of Jackfish Bay. Values progressively increased in samples taken on central and northern transects, respectively. The PWQO was not met at 24 percent of the sample stations.

In a 1990 fish bioassay, conducted to determine the effectiveness of the secondary treatment plant, conditions were found to be much improved (Flood 1990). Where daily dissolved oxygen values ranged from 4.2 to 5.2 mg/L at the Blackbird Creek discharge in July 10 to 14 of 1983, they ranged from 6.8 to 7.3 mg/L in July 26 to 30 of 1990. The lowest dissolved oxygen value measured in the 1983 study was 27 percent saturation, compared to 73 percent in 1990 (Table 3.2).

For a brief period in the spring, the Blackbird Creek discharge sinks, causing the discharge to pool in the deposition areas of Moberly Bay (Beak Consultants 1984). During this period, effluent with low oxygen levels is in direct contact with the bed of Moberly Bay and possibly also with Jackfish Bay proper. This contact would temporarily depress oxygen levels in the area and toxic factors in the effluent would come in direct contact with benthos.

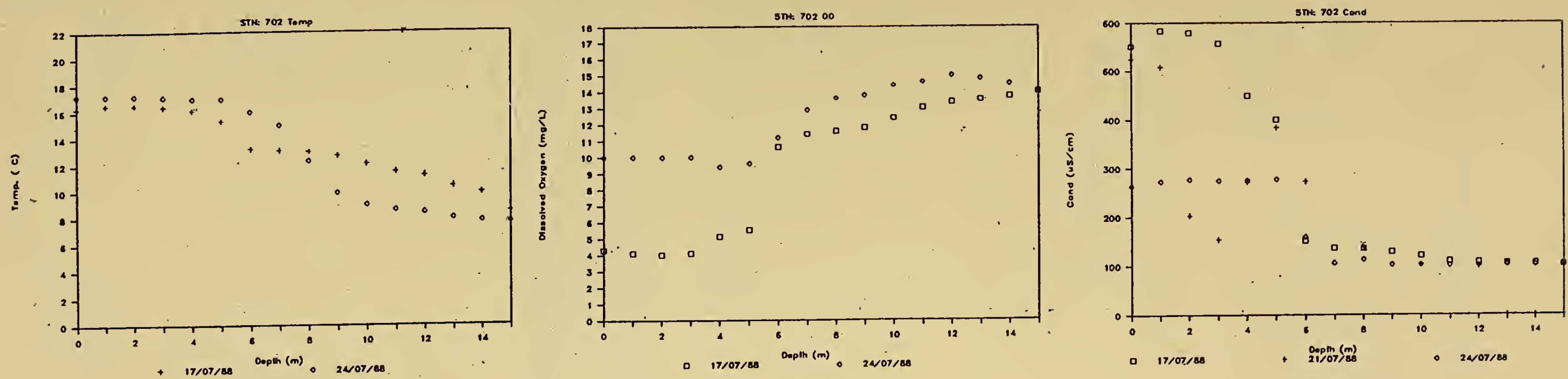
3.1.2.4 Major Ions, pH and Alkalinity

Concentrations of major ions in Moberly and Jackfish Bays were also found to be affected by the effluent plume from Blackbird Creek during the 1987 and 1988 surveys (Sherman 1991). Highest concentrations of cations (calcium, magnesium, sodium and potassium) and anions (sulphate and chloride) along with conductivity measurements were found in the vicinity of Blackbird Creek and values decreased with increasing distance from the discharge (Appendix 3.1). Conductivity provides a measure of the total ionic composition of the water and, hence, provides a useful approximation of the shape and extent of the effluent plume (Figure 3.4). During 1987/88 conductivity values (at 25°C) ranged from 96.0 to 1,590.0 µmhos/cm.

Normally, the largest proportion of cations in Lake Superior is composed of calcium and magnesium (OMOE 1983). However, within the effluent plume in Moberly Bay, sodium dominates the cations. The largest proportion of anions is normally the bicarbonate ion (HCO_3^-). However, the Blackbird Creek discharge resulted in a dominance of chloride ion. Both sodium salts and chloride (in the forms of chlorine) are added during the kraft pulping process.

pH values in Moberly Bay surface waters were below typical Lake Superior values as a result of the effluent discharge. Typical pH in Lake Superior, as shown in the unaffected areas of Jackfish Bay, are 7.8 to 8.0. During 1987 and 1988, the mean pH was lower at all Moberly Bay stations; ranging between 6.1 and 7.9 (Sherman 1991). pH measurements from the entire 1987/88 data set ranged from 5.4 to 8.00. The lower

A STATION 702 - MOBERLY BAY



B STATION 704 - MOBERLY BAY

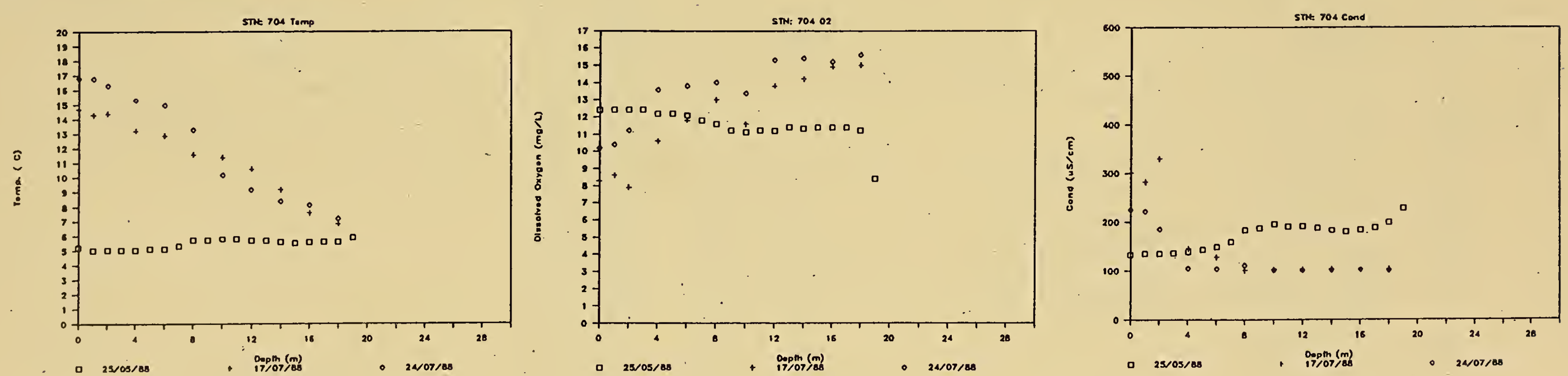
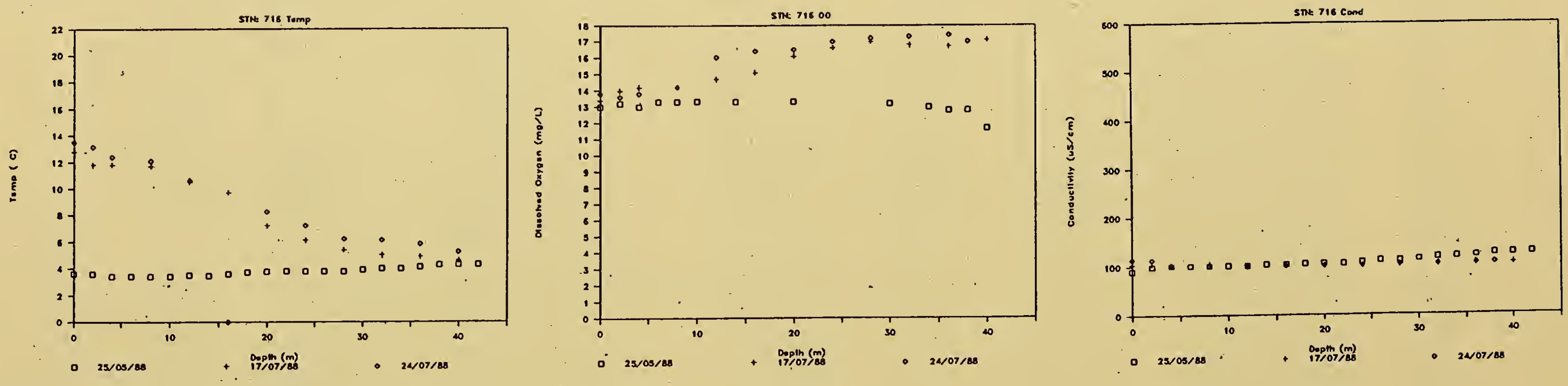


Figure 3.8

Vertical profiles for water temperature (C), dissolved oxygen (mg/L) and conductivity (µS/cm) at stations located in Moberly Bay (702 & 704) in 1987 and 1988 (Sherman 1991).

C STATION 716 - JACKFISH BAY



D STATION 713 - TUNNEL BAY

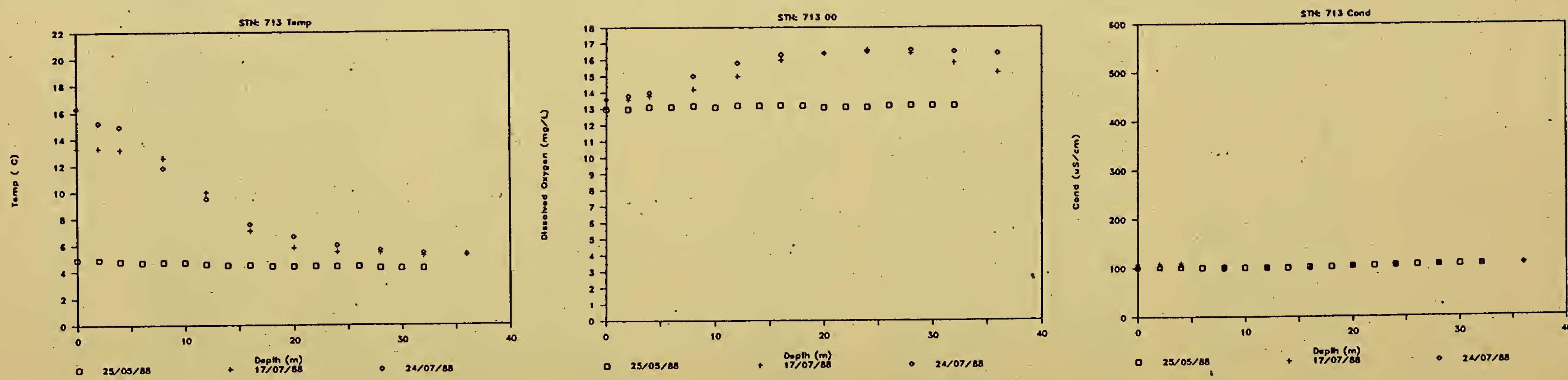


Figure 3.9
Vertical profiles for water temperature (C), dissolved oxygen (mg/L) and conductivity (µS/cm) at stations located in Jackfish Bay (716), and Tunnel Bay (713) (Sherman 1991).

Table 3.2 Dissolved oxygen levels at the fish exposure sites in Jackfish Bay, July 10-14, 1983 and July 26-30, 1990 (Flood 1990).

Exposure Site	1983					1990				
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5
1. Blackbird Creek	6.2	-	6.0	4.9*	4.8*	6.8	6.8	7.3	-	7.2
2. 0.3 km out centre	4.2*	-	3.0†	7.5	3.7†	8.5	10.2	8.5	-	9.4
3. 0.75 km out westshore	6.9	-	2.7†	7.7	4.6†	8.6	8.9	8.6	-	9.5
4. 0.74 km out centre	6.4	-	3.5†	8.1	4.4†	8.7	10.0	9.6	-	9.5
5. 0.75 km out northshore	8.5	-	7.6	8.2	9.6	9.4	10.4	10.0	-	9.2
6. 1.0 km out westshore	7.1	-	3.3†	7.6	4.1†	8.0	9.0	9.5	-	9.7
7. 1.0 km out centre	9.6	-	8.3	8.4	4.7*	9.5	10.0	10.0	-	9.7
8. Cody Island westshore	6.6	-	2.8†	9.4	4.4†	8.0	8.6	9.8	-	9.8
9. Cody Island centre	8.7	-	6.6	8.8	9.1	9.5	10.5	10.0	-	10.1
10. 2.4 km out westshore	8.9	-	9.9	8.8	9.5	9.3	9.7	10.6	-	10.6
11. Little Nick Rock	9.5	-	9.7	9.0	9.7	9.8	10.3	10.0	-	10.5
12. 3.5 km out westshore	9.6	-	10.2	9.5	10.4	9.4	9.8	10.8	-	10.7
13. Mouth of Tunnel Bay	-	-	-	-	-	9.7	10.5	10.5	-	11.9
C1 Control 1 Victoria Bay	10.7	-	-	9.1	9.5	10.8	10.9	11.1	-	11.3
2C2 Control 2 Tunnel Bay	10.3	-	9.8	-	9.9	9.7	10.6	10.5	-	11.4

Note No observations were taken on Day 4 1983 (July 29), due to bad weather conditions.
* dissolved oxygen conditions which did not meet the minimum Provincial Water Quality Objectives for the protection of cold-water biota.
† dissolved oxygen conditions which did not meet the minimum Provincial Water Quality Objective for the protection of warm or cold-water biota.

limit of the PWQO (6.5 to 8.5) was exceeded. In addition, mean pH values at stations 701 (6.35 pH), 803 (6.10 pH) and 806 (6.40 pH) taken during July 1987 were below the lower limit set by the PWQO.

During 1987 the mean alkalinity at all stations including those in Moberly Bay were primarily within the range of 43 to 45 mg/L with occasional values as low as 30.3 and as high as 57.2 mg/L. During July 1988 the mean alkalinity concentrations at stations within Moberly Bay, particularly those closest to the mouth of Blackbird Creek, tended to be much higher. The overall range was 46.5 to 194.0 mg/L with the highest values at the six stations located closest to the mouth of Blackbird Creek (Appendix 3.1). Mean concentrations in Jackfish and Tunnel Bays were generally within the range 44.5 to 52.5 mg/L. Although it would not appear that the effluent had much effect on Moberly or Jackfish Bays during 1987, it clearly resulted in elevated concentrations during 1988. The minimum and maximum recorded values during 1987/88 were 4.00 and 220.00 mg/L respectively.

The PWQO states that alkalinity should not be decreased by more than 25 percent of the natural concentrations. Although it is not clear what the natural concentrations are, the data for 1987 and from Jackfish Bay in 1988 indicate that it is likely about 45 mg/L. Thus there does not appear to be any violation of the PWQO. Short term elevation of the alkalinity in Moberly Bay occurs due to the effluent and although this does not violate any objectives, if sustained, it could result in a change in trophic status in the nearshore waters of the AOC.

3.1.2.5 Nutrients

The effluent causes an increase in plant nutrients, particularly phosphorus and ammonia, within Jackfish Bay. The Provincial Water Quality Guideline for average total phosphorus in lake water is 20 μg/L. This guideline was established to avoid nuisance algal growth, and a guideline of 10 μg/L was established to achieve a higher level of protection from nuisance algal growth. The PWQO for un-ionized ammonia (i.e. NH_3) is 20 μg/L.

The average total phosphorus concentration at all stations in Moberly Bay during 1970 was 51.5 μg/L, well in exceedence of the PWQ Guidelines. Station 10 (Figure 3.10) was the only station in Moberly Bay not to exceed the lower guideline based on an individual sample (8.0 μg/L). The mean total phosphorus concentration of all stations in Jackfish Bay was 11.5 μg/L, which although exceeding the lower guideline was well below the upper guideline. These concentrations clearly show the effect of the Kimberly-Clark effluent on nutrient enrichment in the AOC. Total phosphorus was <10 μg/L at most stations in both Moberly and Jackfish Bays. However, individual exceedences occurred at Station 1 (330 μg/L) located closest to the outlet of Blackbird Creek and Stations 15 (60 μg/L) and 16 (40 μg/L) in Jackfish Bay (Figure 3.1).

Mean total phosphorus concentrations measured during the 1987 and 1988 surveys exceeded the 10 μg/L guideline at all 24 stations (100%) in Moberly Bay during July 1987; at 21 stations (87.5%) in August 1987; and 21 stations (87.5%) during July 1988. The 20 μg/L guideline was exceeded at 21 stations (87.5%) in July 1987; 20 stations (83.3%) in August 1987; and at seventeen stations (70.8%) in July 1988 in Moberly Bay (Appendix 3.1). Those stations with the highest mean total phosphorus were located closest to the mouth of Blackbird Creek (70 to 570 μg/L). Figure 3.10 illustrates the pattern of total phosphorus concentrations in the AOC for individual samples collected in July 1987 and July 1988. All samples ranged from 1 to 770 μg/L. There were no exceedences at the four Tunnel Bay stations (Figure 3.1) for any of the three periods. In Jackfish Bay, the upper guideline was exceeded by mean concentrations at only two stations (12.5%) and only during the July 1987 surveys.

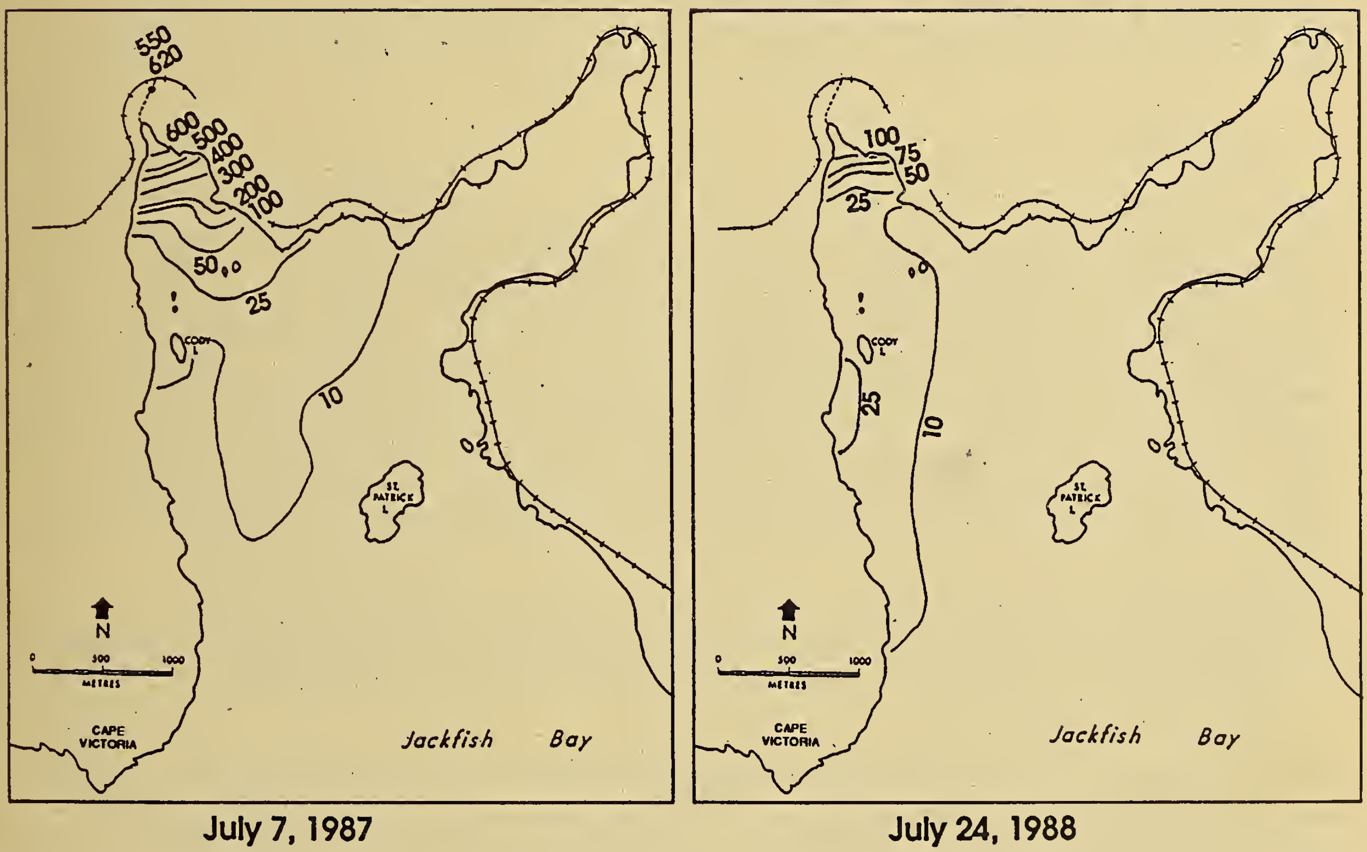


Figure 3.10

Phosphorous concentrations (ug/L) for 1987 and 1988 (Sherman 1991).

The PWQO for un-ionized ammonia is 20 μg/L. Unionized ammonia constitutes only 0.22 to 0.86 percent of total ammonia based on temperature and pH conditions present. This objective was not exceeded in 1987 or 1988. Total ammonia ranged from 6 to 350 μg/L during 1987 and 1988. The highest total ammonia concentrations occurred near the mouth of Blackbird Creek. The mean concentration of total ammonia increased from 1987 to 1988. 1987 mean values ranged from 10 to 40 μg/L with 1988 values ranging from 100 to 170 μg/L (Appendix 3.1).

Even though the total phosphorus data indicate localized eutrophication is occurring within Moberly Bay, high turbidity and colour (as discussed in previous sections) will likely inhibit algae growth in the bay. As these are reduced through pollution abatement efforts, it is expected that phosphorus concentrations in water (and sediment) will support more algal growth than is typical for nutrient poor (oligotrophic) Lake Superior waters.

Based on the data presented above and in Appendix 3.1, it appears that the concentrations of total phosphorus have not improved between 1970 and 1988 and total ammonia concentrations have increased between 1987 and 1988. Although these parameters are suitably diluted by the time the plume reaches the main portion of Jackfish Bay, the potential for eutrophication of the entire area of Moberly Bay is extremely high.

3.1.2.6 Bacteria

Certain bacterial species are pathogens which may cause communicable diseases when present in water utilized by humans for body contact (McNeely et al. 1979). The origin of pathogens is primarily from human and animal wastes and contributed to natural waters via inadequately treated municipal wastewater and runoff contaminated by urban or agricultural sources such as septic systems and animal feed lots. Bacteria are also derived from industrial wastewaters, particularly varieties of *Klebsiella* spp. which are common in pulp mill effluents (Kirby 1986). These waters generally have lower densities of the disease causing bacteria (particularly *Escherichia coli* and *Pseudomonas aeruginosa*). Analyzing water samples for fecal coliform bacteria, particularly, *Escherichia coli* is a useful way of determining the presence of potential human fecal contamination. The PWQO for the swimming and bathing use of water is 100 organisms/100 mL of fecal coliform and 1,000 organisms/100 mL of total coliform bacteria. *Escherichia coli* constitutes 97 percent of the bacteriological flora of human faeces (CCREM 1987) and is a more reliable indicator of health risk associated with gastrointestinal illness. The IJC has recommended a guideline of 23 organisms/100 mL for the seasonal geometric mean of this bacteria (CCREM 1987). *Pseudomonas aeruginosa* is the main etiological agent for ear infections (CCREM 1987). The IJC has recommended that, for the protection of users of nearshore waters against ear infections, no more than 25 percent of analyses should have densities of this bacteria greater than 10 organisms/100 mL which corresponds to a geometric mean density of 1 organism/100 mL (CCREM 1987).

The results of bacteriological analyses conducted during the 1970 survey (OMOE 1972) indicated that geometric means at all stations were well below the PWQO for fecal coliform bacteria with all but one station having <4 organisms/100 mL (Appendix 3.1). The six stations closest to the outfall of Blackbird Creek exceeded the total coliform objective of 1,000 organisms/100 mL (range of 1,200 to 3,900 organisms/100 mL).

The June 1981 survey reported by Kirby (1986) also included a bacteria isolation survey involving Moberly, Jackfish and Tunnel Bays as well as sample locations in Lake Superior immediately to the east of Jackfish Bay and along a 20 km stretch west of Jackfish Bay (OMOE 1983). Bacterial sampling was conducted at most stations during June and July 1981 as well as selected stations (the Kimberly-Clark pumphouse and Blackbird Creek) throughout the year. There were few bacteria in the water in the winter months, whereas numbers increased in the spring and peaked in July and August. Results from this survey indicated that

bacteria levels were high in Moberly Bay and dispersed slowly in Jackfish Bay. Elevated bacterial levels were observed as far west as the pumphouse, south of the Town of Terrace Bay. These were traced back to the effluent discharged by Kimberly-Clark Canada Inc. (OMOE 1981). Due to thermal stratification, the effluent mixed poorly with the receiving waters in Moberly and Jackfish Bays.

Results of the June 1981 sampling indicated densities of *Pseudomonas aeruginosa* of between 300 and 19,000 organisms/100 mL at three stations in Moberly Bay and northern Jackfish Bay (Stations 701, 704 and 710, Figure 3.2) with the highest densities closest to the mouth of Blackbird Creek (Station 701). Densities of *Escherichia coli* ranged between <10,000 to <100,000 at Stations 701, 702, 703, 706 and 707 in Moberly Bay. This organism was not found in the Lake Superior samples during the June surveys. Additional surveys in July 1981 found high densities of *Pseudomonas aeruginosa* between 16 and 6,700,000 organisms/100 mL in Moberly and Jackfish Bays and between <2 to >15,000 organisms/100 mL in Lake Superior samples to the west of Jackfish Bay. Generally the density of *Pseudomonas aeruginosa* decreased from east to west (OMOE 1983).

All densities of *Pseudomonas aeruginosa* and *Escherichia coli* in Moberly Bay during the June surveys exceeded the recommended IJC guidelines. The density of *Pseudomonas aeruginosa* also exceeded the IJC recommended guideline during July 1981 at all stations in Moberly and Jackfish Bays as well as in Lake Superior. Although the density of this organism decreased continuously as the plume passed through Jackfish Bay and westerly along the shore of Lake Superior, it is clear that the effluent discharge from Blackbird Creek is contributing to significant bacterial contamination of the Jackfish Bay AOC and portions of the north shore of Lake Superior.

The 1981 bacteria data was also described briefly by Kirby (1986) who noted high concentrations of heterotrophic bacteria at stations nearest the Blackbird Creek outfall. Although there is no PWQO for heterotrophs, the high densities are indicative of high concentrations of organic pollutants. He also noted violations of the fecal coliform PWQO over all of Moberly Bay and Tunnel Bay as well as the northern and western portions of Jackfish Bay. Fecal coliform levels greater than one million colonies per 100 mL were detected in Moberly Bay and these decreased to between 100 and 19,999 organisms/100 mL in southwestern Jackfish Bay and at Cape Victoria on Lake Superior (Stations 720 and 723, Figure 3.2). The violations occurred at 21 stations (80.8% of stations). However, the analytical test to detect fecal coliforms is particularly sensitive to the presence of *Klebsiella pneumoniae* for which there is some debate regarding health risks (Kirby 1986).

Table 3.3 summarizes the results of bacteriological analyses conducted at selected stations during the 1987 surveys (Sherman 1991). Figure 3.11 shows the distribution of total coliform densities during one survey in July 1987 and one in July 1988. The PWQO for total coliform bacteria was exceeded by geometric means at all stations listed in Table 3.3 except Station 713 which is located Tunnel Bay. Stations 20 and 5 are located within Blackbird Creek upstream of Lake A and downstream of Moberly Lake, respectively. The density of bacteria increased as the effluent passed through the Blackbird Creek system and the highest densities for all bacteria occurred at the downstream Blackbird Creek station and the Moberly Bay station located closest to the creek mouth (Station 701, Figure 3.3). This increase is likely due to bacterial reproduction within the relatively warm waters of the creek. Toxic materials in higher concentrations in the effluent at Station 20 than at Station 5 may also inhibit bacterial growth at this location. The high temporal variability in total coliform density is shown by the results of the individual surveys illustrated in Figure 3.11.
Densities of *Escherichia coli* during July and August of 1987 exceeded the recommended IJC guideline at Stations 5 and 20 as well as at Station 702 in Moberly Bay. The IJC recommended guideline for *Pseudomonas aeruginosa* was likely also exceeded at these stations as well as all other stations except Station 713 in Tunnel Bay.

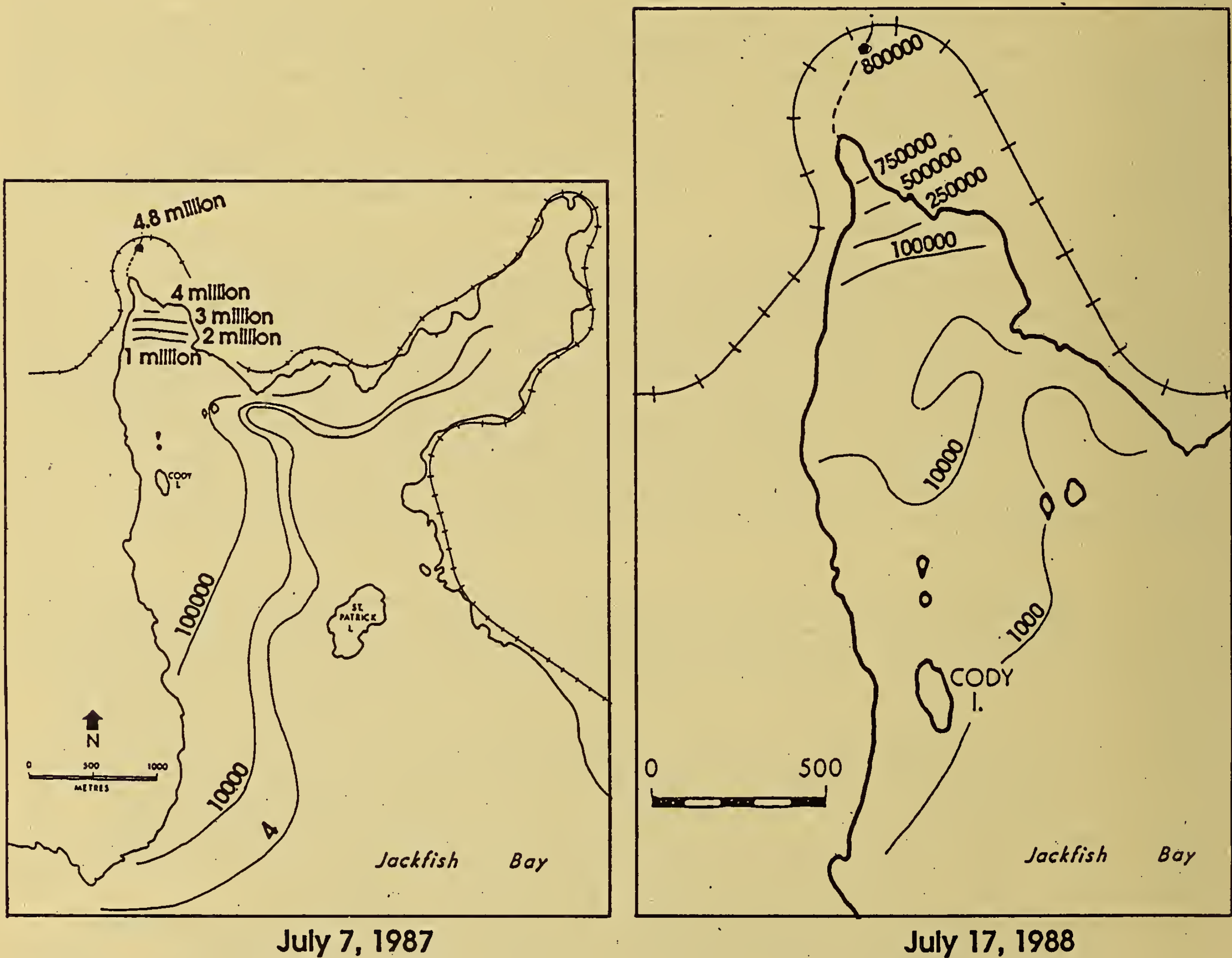


Figure 3.11

Total coliform densities for individual surveys in 1987 and 1988 (Sherman 1991).

Table 3.3 Bacteriological quality at selected stations in the Jackfish Bay AOC during July and August 1987 (Sherman 1991). See Figure 3.3 for station locations.

Station # (samples)	Total Coliform	Total Coliform (BKG)	E. Coli (by MPN)	Pseudomonas aeruginosa	Sulphate Reducers	Heterotroph Bacteria (20 °C) (cnt/mL)
20 (5)	7,096	626,614	<4	29	1,282	130,918
05 (6)	3,749,730	17,458,222	55	113	3,250,873	7,194,490
701 (10)	8,166,677	22,252,926	206	208	3,618,000	8,497,274
702 (7)	947,389	2,492,792	31	63	414,498	2,736,284
811 (8)	266,795	1,070,603	14	32	117,953	1,567,938
704 (4)	257,776	665,868	16	26	892,992	1,388,210
707 (5)	93,157	358,682	<8	19	147,556	1,146,976
716 (2)	12,986	60,168	<3	4	3,000*	266,627
713 (4)	641	3,181	<3	1	194	33,394

Note All values are geometric mean of samples in organisms/100 mL unless otherwise indicated.
* single result

Abundant organic matter deposited in the receiving waters from the mill effluent provides a hospitable habitat for microorganisms such as sulphate reducers and heterotrophic bacteria. Massive densities of both indicator organisms were present at the mouth of Blackbird Creek and into Moberly Bay (Table 3.3). Densities in the effluent were low due to poor conditions for growth of the bacteria within the mill.

High total coliform densities in the effluent likely reflect high densities of the bacterium *Klebsiella* spp. However, the presence of *Escherichia coli* and *Pseudomonas aeruginosa* in densities exceeding the IJC recommended guidelines during 1981 and 1987 is of some concern as it suggests a potential health risk associated with body contact recreation in Moberly and Jackfish Bays as well as to the west along the shore of Lake Superior. The presence of *Escherichia coli* also indicates a significant mammalian faeces component to the wastewater which may include human sources.

3.1.3 Metals

The PWQOs for metals were established to protect aquatic life against the toxic effects of elevated concentrations (OMOE 1984). Metals are known to have the potential to bioaccumulate (Callaghan et al. 1979).

Metals were not measured as part of the 1970 OMOE survey. During the 1981 surveys, metals were only measured at Station 701 which was located closest to the mouth of Blackbird Creek (Kirby 1986). The results of the June and September surveys are provided in Table 3.4 along with the respective PWQOs and

Table 3.4 Concentrations (mg/L) of metals in whole water at station 701 in Jackfish Bay, 1981 (Kirby, 1986).

		Cd	Cr	Cu	Ni	Hg	Pb	Zn
Provincial Water Quality Objective		0.0002	0.100	0.005	0.025	0.00020	0.005	0.030
GLWQA Objective		0.0002	0.050	0.005	0.025	0.00020	0.010	0.030
June 23	9:00 a.m.	-	-	-	-	-	-	-
	11:00 a.m.	0.003*	0.015	0.010*	0.005	0.00330*	0.042*	0.050*
	1:00 p.m.	0.002*	0.020	0.009*	0.007	0.00110*	0.039*	0.060*
	3:00 p.m.	0.002*	0.011	0.010*	0.004	0.00300*	0.048*	0.050*
June 24	9:00 a.m.	0.002*	0.009	0.040*	-	0.00014	-	0.050*
	11:00 a.m.	0.002*	0.008	0.008*	-	0.00008	-	0.030
	1:00 p.m.	0.003*	0.009	0.006*	-	<0.00005	-	0.040*
	3:00 p.m.	0.003*	0.011	0.020*	-	<0.00005	-	0.040*
June 25	9:00 a.m.	0.003*	0.012	-	-	-	-	0.050*
	11:00 a.m.	0.003*	0.011	-	-	-	-	0.050*
	1:00 p.m.	0.002*	0.007	-	-	-	-	0.050*
	3:00 p.m.	0.002*	0.009	-	-	-	-	0.040*
Sept 14	9:00 a.m.	0.007*	0.023	1.000*	0.028*	<0.00005	0.004	0.046*
	11:00 a.m.	0.002*	0.017	1.200*	0.012	<0.00005	0.002	0.042*
	1:00 p.m.	0.002*	0.013	2.000*	0.017	0.00007	0.001	0.090*
	3:00 p.m.	0.002*	0.011	0.008*	0.015	0.00005	0.001	0.038*
Sept 15	9:00 a.m.	0.002*	0.011	0.072*	0.014	<0.00005	0.001	0.040*
	11:00 a.m.	0.002*	0.013	0.047*	0.014	<0.00005	0.001	0.031*
	1:00 p.m.	0.002*	0.011	0.008*	0.017	<0.00005	0.001	0.028
	3:00 p.m.	0.002*	0.011	0.008*	0.015	<0.00005	0.001	0.029
Sept 16	9:00 a.m.	-	0.015	0.003	0.016	0.00008	0.001	-
	11:00 a.m.	-	0.009	-	0.016	<0.00005	0.001	-
	1:00 p.m.	-	-	-	-	<0.00005	-	-
	3:00 p.m.	-	-	-	-	<0.00005	-	-

* exceeds most stringent guideline.
\- not sampled.

GLWQA Specific Objectives. The PWQOs and the GLWQA Specific Objectives for cadmium (100% of samples), copper (93.8%), nickel (7.7%), lead (23.1%) and zinc (84.2%) were exceeded at Station 701 (Table 3.4). The maximum concentration of copper was 400 times the objective and that of zinc was 3 times the objective (Kirby 1986). Cherwinsky and Murray (1986) had estimated that effluent dilution in Moberly Bay is only 20:1 at about 6 km from the discharge, indicating that elevated metals could still be expected further out from this station.

Mercury was sampled at 11 stations including Moberly and Jackfish Bay locations. The Objectives were exceeded at all sample locations on June 23. These included Stations 701 (Table 3.4), 702, 704, 707, 709 to 714 and 719 (Figure 3.2). In all, 19.1 percent of samples exceeded the PWQO and the GLWQA Specific Objective. Mercury concentrations decreased as distance from the mill discharge increased, indicating that the mill effluent was the source of mercury. Kirby (1986) concluded that the mill effluent was the most likely source of the metal contamination although he noted that other sources of zinc and copper may be present due to high concentrations on September 14, before the effluent would have reached the mouth of Blackbird Creek following start-up operations.

Metal concentrations were determined for all stations during the July and August 1987 and July 1988 surveys (Sherman 1991). The results for each station are provided in Appendix 3.1 and the sample locations are shown in Figure 3.3. Table 3.5 summarizes the range in station means for each metal and the percent exceedences of PWQO and GLWQA Specific Objectives by all station means.

Exceedences of guidelines occurred in Moberly Bay for aluminum, beryllium, iron, mercury, cadmium, chromium, copper, nickel, lead and zinc (Table 3.5). Only copper and lead mean concentrations exceeded guidelines in Tunnel Bay and only during one survey (July 1987). Guidelines were exceeded by station means in Jackfish Bay during two of the three surveys (July and August 1987). Exceedences occurred for mercury, cadmium, copper, lead and zinc. The frequency of exceedences varied considerably by parameter and date of survey, however, most guideline exceedences occurred during the July 1987 surveys and the fewest occurred during the 1988 surveys. Except for beryllium and chromium, the maximum values recorded for metals in water during 1987/88 exceeded the PWQO by one to two orders of magnitude (Table 3.5). Maximum values of beryllium exceeded the PWQO by five times and chromium was exceeded by 1.3 times.

3.1.5 Organic Contaminants

3.1.5.1 Phenolics

Phenolic substances are organic compounds which may occur naturally in trace amounts as they are released by aquatic plants and decaying vegetation (McNeely et al. 1979). Major sources of phenolic compounds are released to the aquatic environment from the distillation of coal and wood, oil refining, chemical production, animal and human waste and phenolic pesticides. The PWQO to protect against tainting of edible fish flesh for reactive phenolics is 1 $\mu g/L$.

During the 1981 survey by OMOE, phenolic substances were detected in the Kimberly-Clark mill effluent (Kirby 1986). The PWQO was exceeded in Moberly Bay at stations up to 4 km from the mouth of Blackbird Creek in June and up to 2.5 km in September. The maximum concentrations measured were 380 $\mu g/L$ in June and 244 $\mu g/L$ in September at Station 701 (Figure 3.2), closest to the mouth of the Creek (Kirby 1986). However, due to their relative instability, concentrations declined rapidly between stations 701 and 702.

Because the toxicity of specific phenolic compounds, as well as their ability to impart taste and odour, varies greatly, measurements were also made for trichlorophenol, tetrachlorophenol, pentachlorophenol, phenol and guaiacol. The corresponding PWQOs and concentrations of these parameters at 11 stations in Moberly Bay, Tunnel Bay and northern Jackfish Bay are provided in Table 3.6. Stations near the head of Moberly Bay

Table 3.5 Ranges in station means and percent exceedence by station means of PWQO and GLWQA Specific Objectives (for most stringent objective) for metals analyzed in Moberly Bay (MB), Jackfish Bay (JB) and Tunnel Bay (TB) during 1987 and 1988 (Sherman 1991). All values are in $\mu g/L$.

	Al	As	Be	Fe	Hg	Cd	Cr	Cu	Mn	Ni	Pb	Zn
PWQO	75	100	10	300	0.2	0.2	100	5	-	25	5	30
GLWQA	-	50	-	300	0.2	0.2	50	5	-	25	10	30
Total Data Set Range	ND-2,100	ND-18	ND-50	ND-2,600	ND-70	ND-40	ND-130	ND-410	ND-590	ND-100	ND-220	ND-380
Bay	JULY 1987											
MB (23 STA)	ND-1,000 (60.9%)	ND	ND-37 (17.4%)	9-1,210 (17.4%)	ND-13 (13%)	ND-7 (8.7%)	ND-110 (13%)	ND-177 (43.5%)	16-507	ND-70 (21.7%)	ND-113 (56.5%)	ND-200 (30.4%)
JB (4 STA)	ND-55	ND	ND-4	18-80	ND-13 (25%)	ND	ND-7	ND-11 (50%)	ND-31	ND-6	ND-112 (75%)	3-135 (75%)
TB (3 STA)	ND-39	ND	ND-6	37-62	ND	ND	ND-6	ND-6 (33.3%)	ND-7	ND-7	7-23 (100%)	ND-9
	AUGUST 1987											
MB (21 STA)	ND-612 (57.1%)	ND	ND-23 (9.5%)	ND-1,140 (19%)	ND-12 (4.8%)	ND-11 (23.8%)	ND-40	ND-23 (71.4%)	ND-313	ND-23	ND-63 (69.6%)	ND-60 (9.5%)
JB (4 STA)	16-41	ND	ND	28-74	ND	ND-0.4 (25%)	ND-3	ND	6-17	ND	ND	ND-4
TB (3 STA)	ND-16	ND	ND	11-45	ND	ND	ND	ND	2-3	ND-3	ND-4	ND
	JULY 1988											
MB (22 STA)	16-508 (45.5%)	ND	ND	ND-505 (9.1%)	ND-35 (18.2%)	ND-4 (13.6%)	ND-45	ND-18 (36.4%)	7-348	ND-13	ND-20 (13.6%)	ND-39 (4.5%)
JB (4 STA)	ND-35	ND	ND	ND-50	ND	ND	ND-2	ND	ND-20	ND	ND	ND-1
TB (3 STA)	13-15	ND	ND	ND-24	ND	ND	ND-2	ND	3-6	ND	ND	1

Table 3.6 Concentrations (μg/L) of phenolic compounds detected in Moberly Bay (MB), Tunnel Bay (TB) and Jackfish Bay (JB) in 1981 (Kirby, 1986). Station locations are shown in Figure 3.2).

Station	Bay	Date	TCP	TTCP	PCP	Phenol	Guaiacol
Provincial Water Quality Objective			18.0	1.0	0.5		*
701	MB	June 23	1.30	0.60	0.54	ND	-
		June 24	ND	0.25	0.25	ND	235
		June 25	0.23	0.13	-	ND	265
702	MB	June 23	ND	0.30	0.25	ND	119
		June 24	ND	0.25	ND	ND	77
704	MB	June 2	0.08	0.08	0.11	ND	48
		June 24	0.08	0.08	0.19	ND	24
705	MB	June 23	ND	ND	0.06	-	-
		June 24	ND	ND	ND	-	-
706	MB	June 24	ND	0.07	0.05	-	-
707	MB	June 23	ND	0.06	0.07	ND	18
710		June 23	ND	ND	ND	-	-
713	TB	June 23	-	-	-	ND	ND
701	MB	Sept 14	ND	ND	0.40	21.1	ND
		Sept 15	ND	ND	0.15	150.0	139.2
		Sept 16	ND	ND	ND	42.2	149.4
702	MB	Sept 14	ND	ND	ND	ND	ND
704	MB	Sept 14	ND	ND	ND	ND	ND
707	MB	Sept 14	ND	ND	ND	ND	ND
709	JB	Sept 14	ND	ND	ND	ND	ND
710	JB	Sept 14	ND	ND	ND	ND	ND
712	JB	Sept 14	ND	ND	ND	ND	ND
714	JB	Sept 14	ND	ND	ND	ND	ND

TCP trichlorophenol
TTCP tetrachlorophenol
PCP pentachlorophenol
ND not detected
- not sampled
* no PWQO, however Shaman and Palenshky (1973) recommended threshold concentration for not impairing fish flavour is 100 μg/L.

(Stations 701, 702, 704 and 706) had the most frequent detections of phenol compounds. However, all concentrations were below the respective PWQO with the exception of pentachlorophenol at Station 701 nearest the mouth of Blackbird Creek on June 23, 1981. In addition, guaiacol was detected at levels which taint fish flesh (100 μg/L) at Stations 701 (June 23 and 25, Sept. 15 and 16) and 702 (June 23, Table 3.5). Kirby (1986) indicated that the mill was the most likely source of phenols detected in Jackfish Bay during the June and September surveys.

Trace amounts of phenolic compounds, particularly pentachlorophenol and 2,4,6-trichlorophenol, were detected at Station 701, near the Blackbird Creek discharge, in 1987 and 1988 (Sherman 1991), but were not detected further out in the Bay.

3.1.5.2 Resin and Fatty Acids

Resin and fatty acids are components of pulp mill liquors and effluents and are significant and primary sources of toxicity in pulp mill effluents (McLeay et al. 1986). Resin acids are derived from resins found in the wood of coniferous trees, and are released in receiving waters as extractives during the pulping process (Taylor et al. 1988). Fatty acids are formed from fats stored in the wood to provide winter food reserves for the tree. These fats are hydrolysed during pulping to form fatty acids.

During the 1981 surveys, abietic acid and isopimaric acid concentrations exceeded the 96 hour LC^{50} concentration for trout (1.1 mg/L and 0.7 mg/L, respectively) at Station 701 near the mouth of Blackbird Creek (Kirby 1986).

Resin and fatty acids were detected only periodically during the 1987 and 1988 surveys in trace amounts at Station 701 near the creek outfall (Sherman 1991). Dehydroabietic acid exceeded the PWQO (12.0 μg/L at pH 7.5) in Moberly Bay during 1987 and 1988. The highest values (>300 μg/L) occurred in 1988. The distributions of dehydroabietic acid during individual surveys in 1987 and 1988 are shown in Figure 3.12. During these surveys, the PWQO for dehydroabietic acid was exceeded at nine stations in the head of Moberly Bay including 701, 702 and 803-809 (Figure 3.3).

Although the concentrations of these acids in water decrease rapidly from the discharge point (Figure 3.12), it has been suggested (Sherman 1991) that resin acids associated with foam or particles in the effluent may be carried out into the Bay and sedimented, where they would break down more slowly than they otherwise would (see Section 3.2.4.2).

Preliminary results from sampling during July 1990, following start-up of the secondary treatment system at the mill, indicated that dehydroabietic acid was not detected in Moberly Bay in daily samples collected over a five day period (K. Flood, OMOE, pers. com.). The only resin or fatty acid measured in the effluent and Moberly Bay was palmitic acid, but only in trace amounts (maximum 26 μg/L). None of the resin acids were detected in Moberly or Jackfish Bay (K. Flood, OMOE, pers. com.).

3.1.5.3 Volatile Organohalides

Chloroform, which is formed in the full bleached kraft pulp mill process, was elevated for a considerable distance into Moberly Bay and beyond. Results for individual surveys during 1987 and 1988 are shown in Figure 3.13. There is no PWQO or GLWQA Specific Objective for chloroform. No other volatile organic compound was detected in the open water samples.

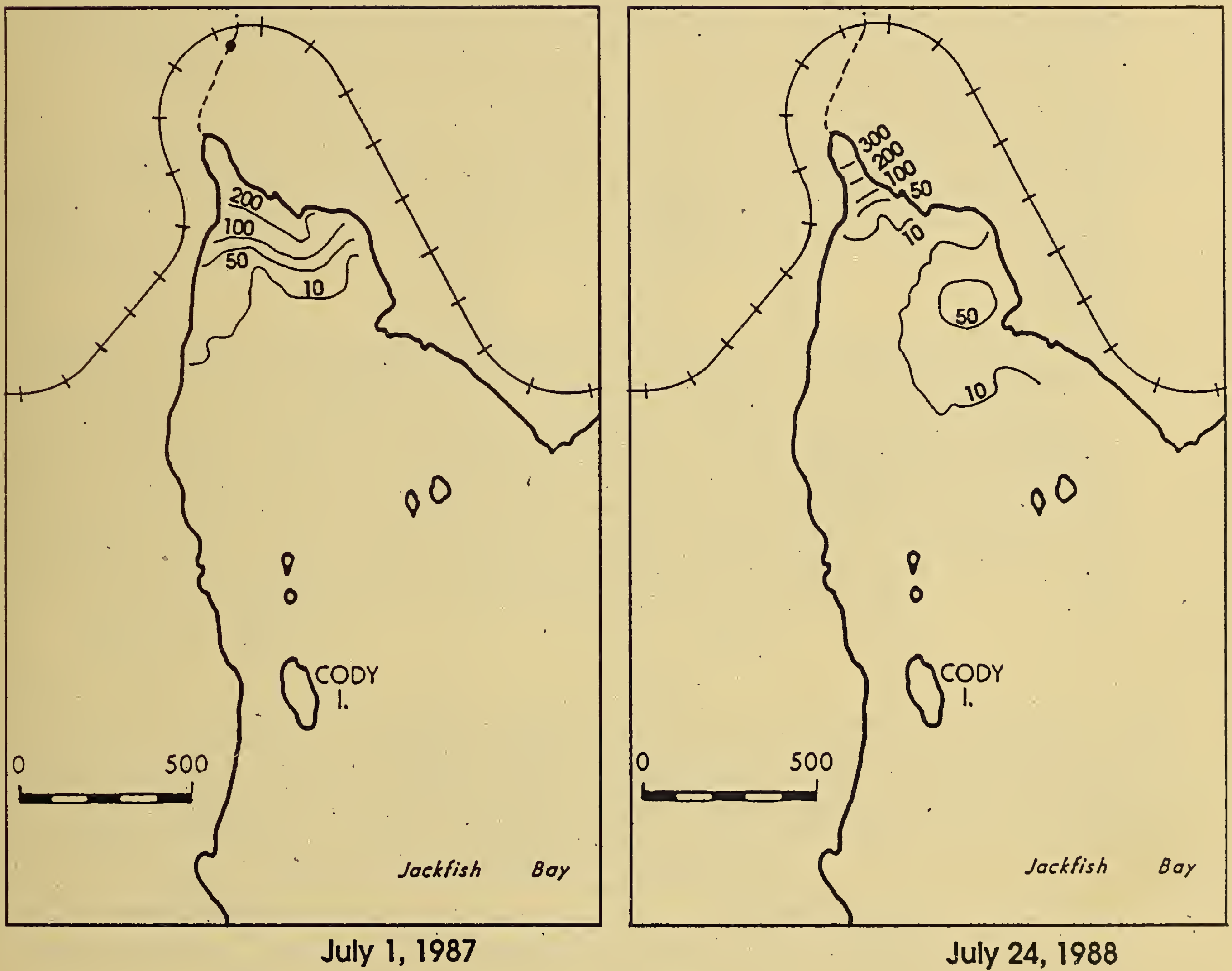


Figure 3.12

Concentration of dehydroabletic acid (µg/L) for individual surveys in 1987 and 1988 (Sherman 1991)

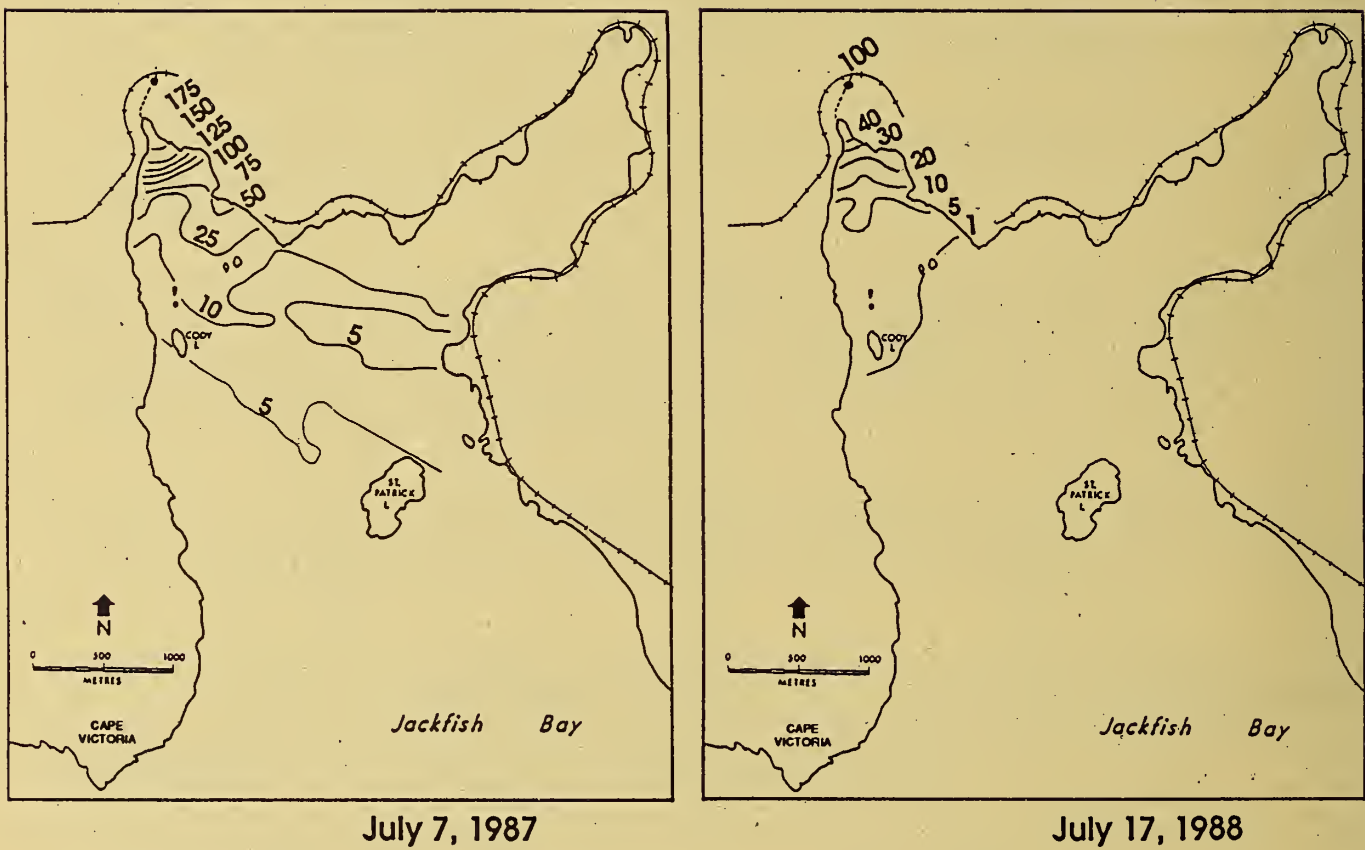


Figure 3.13

Chloroform concentrations (µg/L) for individual surveys in 1987 and 1988 (Sherman 1991).

3.1.5.4 Other Organic Chemicals

Traces of γ-BHC, hexachlorobenzene, total trihalomethanes and phenoxy herbicides were detected in the immediate vicinity of the mouth of Blackbird Creek (Sherman 1991).

3.1.6 Water Quality Summary

Water quality surveys undertaken during 1970, 1981 and 1987/88 indicated a plume of contamination in Jackfish Bay resulting from the discharge of effluent from the Kimberly-Clark Canada Inc. pulp mill via Blackbird Creek. Surface waters, situated above the hypolimnion layer, are most affected in terms of higher concentrations and more frequent exceedences of PWQOs and GLWQA Specific Objectives than bottom waters. Although the extent and impact of the plume varies depending on wind and current direction, the most heavily impacted zone includes all of Moberly Bay and the northern and western portions of Jackfish Bay. Nearshore waters of Lake Superior to the west of Jackfish Bay are also affected by the plume as shown by stations located offshore of Cape Victoria and by bacterial surveys. Elevated densities of several bacterial species occurred in densities exceeding PWQOs or IJC recommended levels as far west as Pumphouse Bay south of the Town of Terrace Bay. Although Tunnel Bay is mostly outside the plume, occasional guideline exceedences (particularly metals and bacteria) occur due to individual wind events moving the surface plume to the northeast.

The most recent water quality surveys for the Jackfish Bay AOC were undertaken during July and August 1987 and July 1988. These surveys identified concentrations of contaminants resulting in exceedences of PWQOs and/or GLWQA Specific Objectives for turbidity (secchi disc), dissolved oxygen, pH, total phosphorus, total coliform bacteria, fecal coliform bacteria, aluminum, beryllium, cadmium, chromium, copper, iron, mercury, nickel, lead, zinc and dehydroabietic acid. The dissolved oxygen objective was also violated during 1990 studies, however, dehydroabietic acid was not detected in Moberly Bay in 1990. The IJC recommended guideline for *Pseudomonas aeruginosa* was also exceeded during the 1987/88 and earlier investigations. Total phenolics and pentachlorophenol were exceeded during the 1981 surveys. Most exceedences occur in the upper half of Moberly Bay, however, exceedences occur regularly for some metals and bacteria in much of Jackfish Bay and occasionally in Tunnel Bay.

3.2 SEDIMENT QUALITY

A fundamental requirement in remediating water quality problems in Areas of Concern is to assess sediment contamination and the effects of the sources of contamination on the AOC. The extent of sediment contamination must be known quantitatively in order to support effective remedial actions such as sediment removal, burial or destruction. Full bleached kraft pulp mill effluents have long been associated with adverse effects on sediment quality and sediment dwelling aquatic life of receiving waters in the Great Lakes Basin (Dymond and Laporte 1952, German and Pugh 1969, McLeay et al. 1986).

Moberly Bay, Tunnel Bay and the main body of Jackfish Bay represent three deposition basins separated by shoals or bedrock sills. Moberly Bay is sheltered from wind and wave action by high hills and a constricted entrance formed by shoals and islands. Jackfish Bay is protected from the open waters of Lake Superior by a shoal and an island. The longest fetch is oriented north-northeast with a distance of 5 km. The bed of Jackfish Bay consists of a wide range of materials including bedrock, glaciolacustrine clay, sands and coarse glacial till.

Bottom sediments were sampled for contaminant analysis during surveys in 1981 (Kirby 1986) and 1987/88 (Sherman 1991). Sample stations for the 1981 survey are shown in Figure 3.14 and for the 1987 survey in Figure 3.15. Sampling locations for the 1987 survey were chosen specifically to represent the deposition

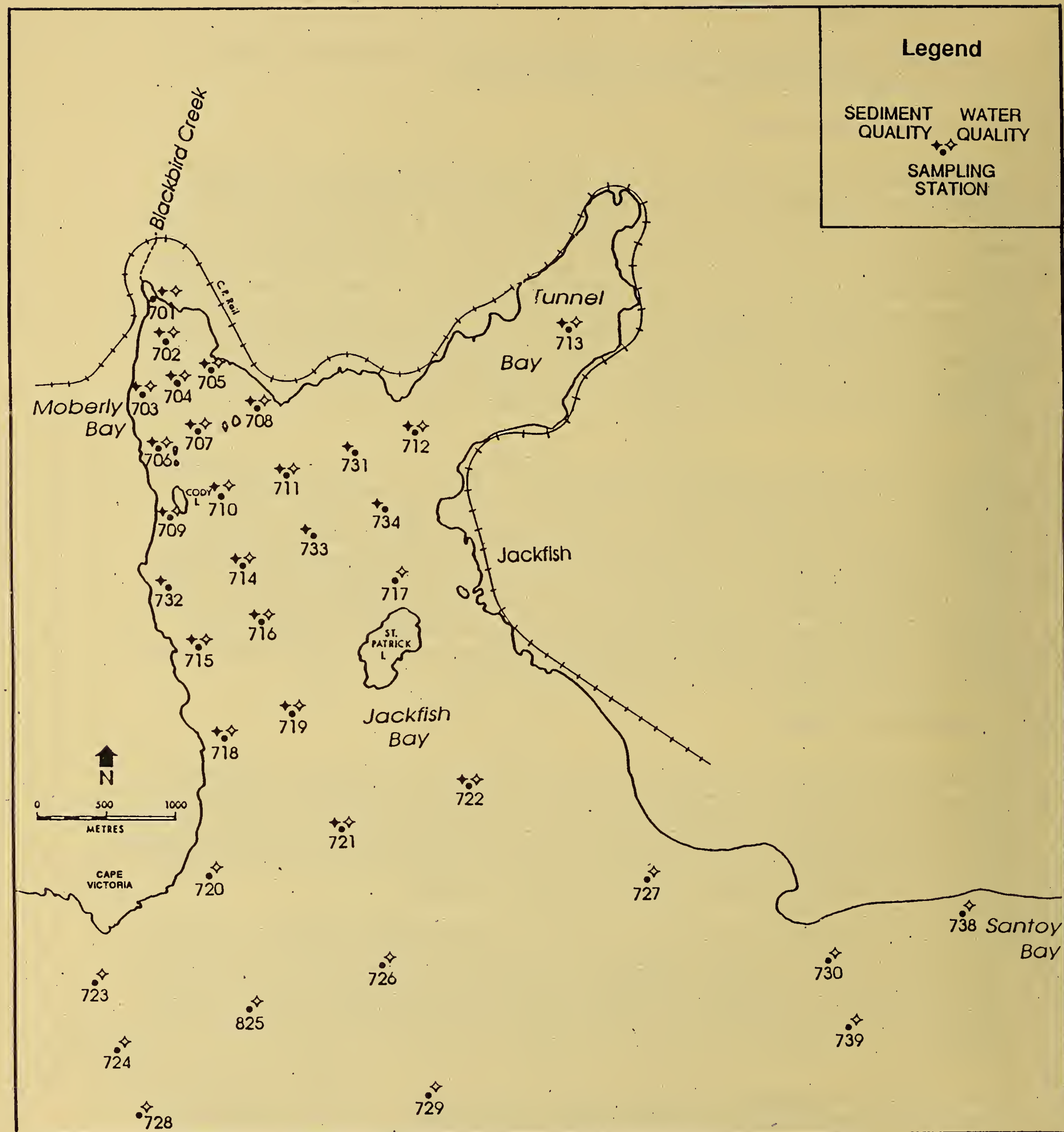


Figure 3.14

Sampling station locations for the 1981 sediment survey in Jackfish Bay (Kirby 1986)

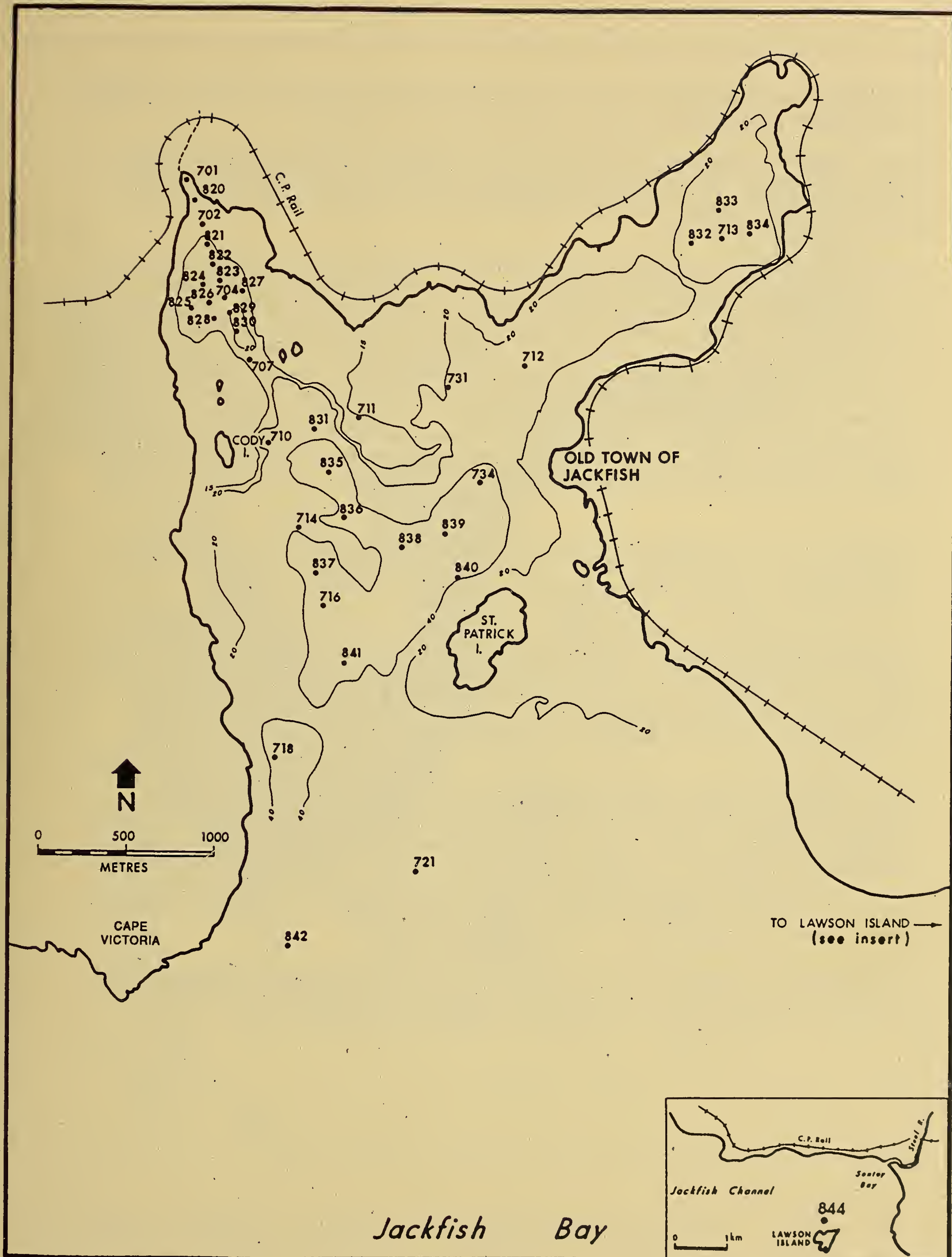


Figure 3.15

Sediment sampling stations for the 1987 sediment survey (Sherman 1991).

basins within Jackfish Bay (Figure 3.16). The basins are marked by the areas of fine-grained 'mud' deposits which represent recently deposited sediment and associated trace contaminants.

Many contaminants of concern have a tendency to adsorb or bind with fine-grained (especially organic) particles. The results of the 1981 and 1987 sediment surveys will be compared to the draft Provincial Sediment Quality Guidelines (PSQG) and the OMOE Guidelines for Open Water Disposal of Dredged Material Guidelines (OWDG).

The revised OWDG were established in 1978 and have been used extensively to determine whether dredged materials are suitable for open water or confined disposal. However, the particular contaminant concentrations were not based on known biological effects. Biologically-based guidelines (PSQG) have since been established to replace the OWDG. The PSQG guidelines released by the Ontario Ministry of the Environment in March 1991 (Persaud et al. 1991) "are intended to provide guidance during decision-making in relation to sediment issues, ranging from prevention to remedial action". They are based on the need to protect benthic communities and to prevent biomagnification from contaminated sediments. The guidelines are based on three levels of ecotoxic effects including: (1) the No-Effect Level (NEL) - the level at which no toxic effects have been observed on aquatic organisms; (2) the Lowest-Effect Level (LEL) - the level of contamination which can be tolerated by the majority of benthic organisms; and (3) the Severe-Effect Level (SEL) - the level at which pronounced disturbance of the sediment dwelling community can be expected (Persaud et al. 1991).

The physical and chemical characteristics of the surficial sediments (the top three cm) is described in the following sections. Where available, the quality of suspended sediment sampled from the mill effluent (effluent canal at Highway 17) and near the mouth of Blackbird Creek are also presented.

As mentioned, trace contaminants are generally associated with finer sediments such as silts and clays than with coarser sands. The results of the 1981 survey indicated that elevated trace contaminant levels in the Jackfish Bay AOC were associated with finer material (Kirby 1986). However, these observations were based on grab samples which were not fully representative of the depositional basins. A better understanding of the impact of mill effluent on sediments required a map of sediment characteristics identifying the exact extent of fine sediment distribution.

In 1987, a sonar survey was conducted of Jackfish Bay in order to develop a map of sediment characteristics for the entire area (Sherman and McMillan 1988). Sonar is a useful means of continuously mapping sediments. The resultant map from this survey is given in Figure 3.16. The sonar survey determined that fine-grained sediment ('mud') is accumulated in the deepest deposition areas. The sediment in these areas was found to be relatively uniform with the exception of Moberly Bay where the organic-rich sediment characteristic of the deposition basin (termed 'gyttja') has been influenced by the mill over the years. The authors were also able to identify areas of glacial till, glaciolacustrine clay and ice scouring. These results were confirmed by comparison with grab samples taken concurrently.

Sonar mapping also identified the location of large 'sand waves' also referred to as 'megaripples', which are located at the openings of Moberly and Jackfish Bays. These sand waves indicate that relatively strong currents enter or leave each bay with the potential for significant movement of sediments.

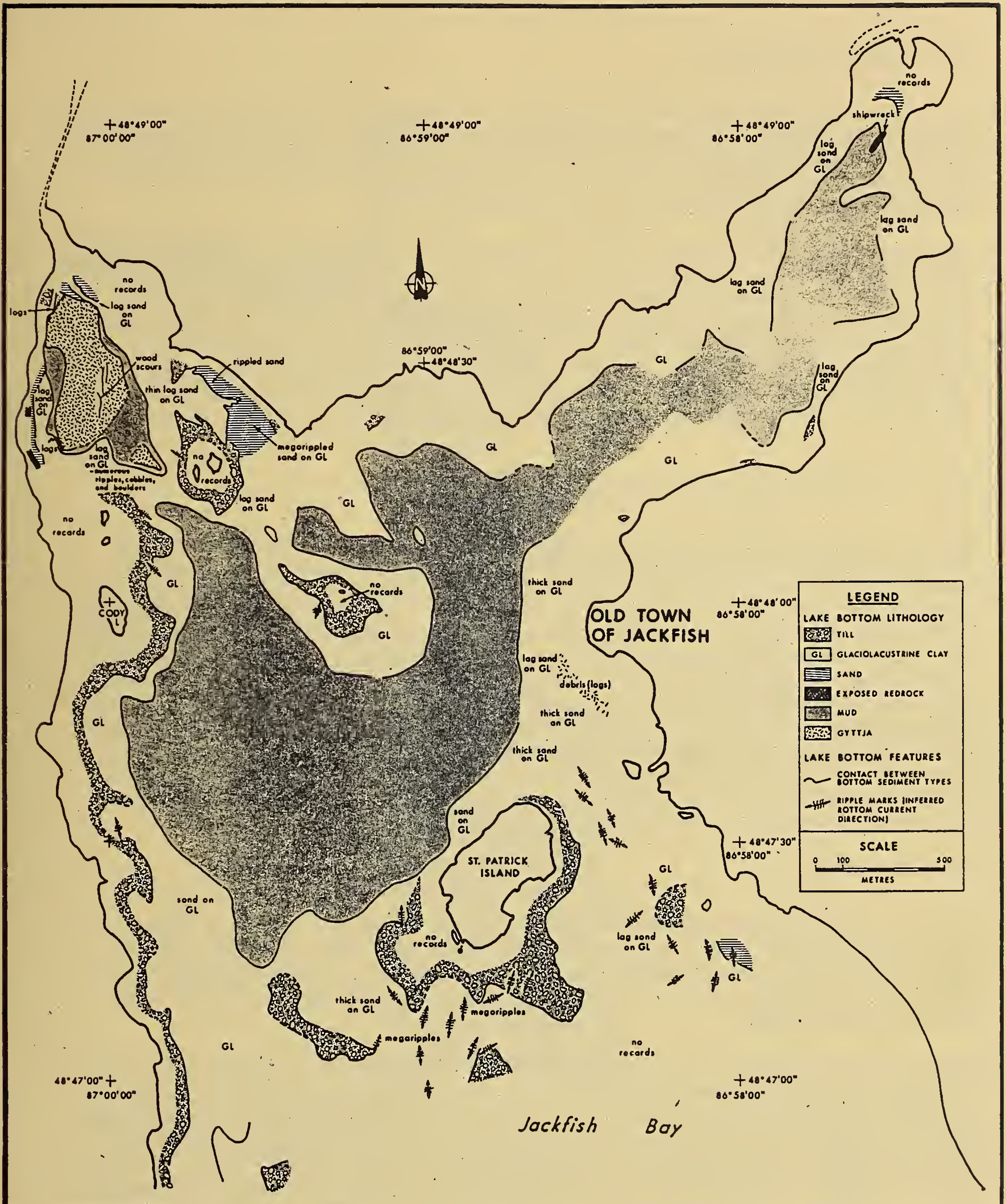


Figure 3.16

Lake bottom lithology of Jackfish Bay as determined by sonar survey October 19-30, 1987 (Sherman 1991).

3.2.1 Physical Description

The particle size of sediment sampled in 1987 was generally greater than 60 percent clay and silt (i.e., >62 micrometres in diameter). Exceptions were higher coarse sand and gravel content from Stations 701 (at the mouth of Blackbird Creek, Figure 3.15) and 711 (on the edge of a shoal in Jackfish Bay). When these stations were excluded, the stations representing the three depositional areas (Figure 3.16) were found to be statistically similar with respect to particle size (Sherman 1991).

Eh (measured in mvolts) is a physical measure of oxidizing and reducing conditions in sediments. Positive values are an indication of oxidizing conditions in the interstitial waters (between the sediment particles) whereas negative values are an indication of a complete lack of oxygen and reducing conditions. The occurrence of reducing conditions in sediment pore waters can be used as an indication of contamination, particularly due to the presence of organic carbon and metals. The most severe reducing conditions were found in Moberly Bay (Figure 3.17). The sediments at most stations in Moberly Bay had a strong odour of hydrogen sulphide (H_2S), a sign of reducing conditions and a lack of oxygen in the surficial sediment. The odour was also noted in Jackfish Bay, but only at stations near the mouth of Moberly Bay (Stations 710, 831, and 714).

3.2.2 Oil and Grease Contamination

Another indication of the degree of sediment contamination is provided by the concentration of oil and grease in the sediments. The mean concentrations of oil and grease (solvent extractables) at stations sampled during the 1987 survey are provided in Figure 3.18. Values fluctuated widely throughout the three deposition basins with ranges in mean concentrations of 4,295 to 37,450; 102 to 10,820; and 15,000 to 16,000 μg/g in Moberly Bay, Jackfish Bay, and Tunnel Bay deposition areas, respectively (Sherman 1991). The total range of individual samples was from 21 to 58,300 μg/g (Sherman 1991). These are comparable to the concentration ranges measured during the 1981 surveys which ranged between 550 and 34,600 μg/g in Moberly Bay and 430 and 6,150 μg/g in Jackfish Bay (Table 3.7). The OMOE Dredge Disposal Guideline for oil and grease of 1,500 μg/g was exceeded in each depositional area during surveys in 1981 (66.7% of samples) and 1987 (85.7% of station means). The guideline was even exceeded in Tunnel Bay which is removed from the direct influence of the mill effluent. Although the highest concentrations occurred in Moberly Bay, nearest the mill outfall, the wide variation in each basin suggests that there is no direct relationship between the mill effluent and oil and grease levels in the sediments.

3.2.3 Nutrients

Total organic carbon provides an indication of the enrichment of the sediments with organic matter. The matter can originate from natural sources such as dead algae and other aquatic organisms and organic matter from the pulping process. The PSQG Lowest Effect Level (LEL) is 1 percent (10 mg/g) and the Severe Effect Level (SEL) is 10 percent (100 mg/g) with respect to the potential for disturbance of the sediment dwelling community.

The mean total organic carbon concentrations in the sediments sampled during the 1987 surveys are shown in Figure 3.19. The highest mean concentrations were in Moberly Bay with a range of 42 to 210 mg/g (excluding Station 701). Mean concentrations at four stations (28.6%) in Moberly Bay exceeded the SEL (Stations 702, 821, 822, 825) and six station means from the three depositional basins exceeded the LEL (17.1%). Jackfish Bay ranged from 5 to 56 mg/g and Tunnel Bay ranging from 27 to 33 mg/g. The total range of all bottom sediment samples was 5 to 250 mg/g (Sherman 1991). Values generally decreased from high concentrations in the suspended sediment of the effluent to lower concentrations in bottom sediment

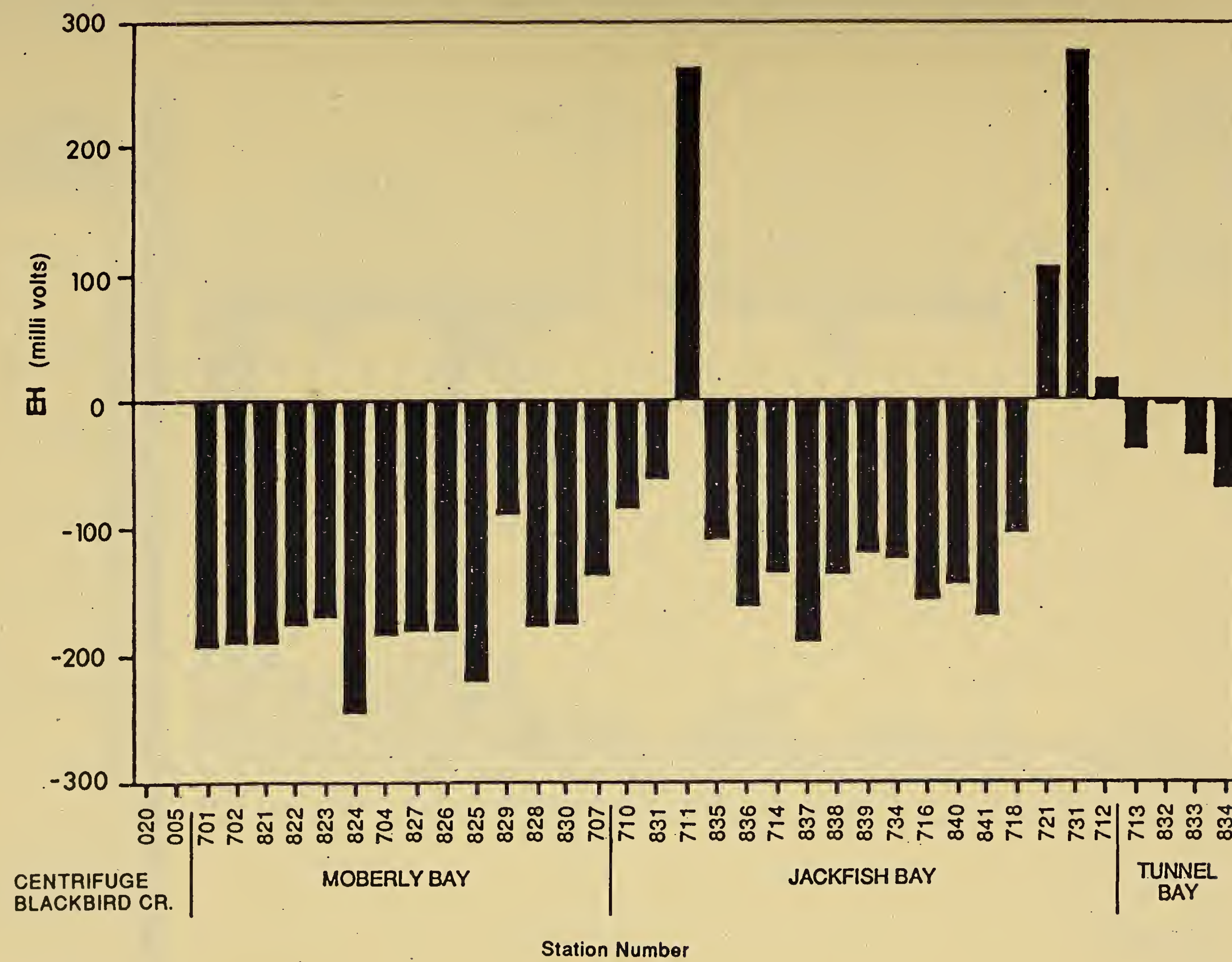


Figure 3.17

Eh values for Jackfish Bay bottom sediment interstitial waters, 1987 (Sherman 1991). Station locations are shown in Figure 3.15. Negative values indicate reducing conditions and positive values indicate oxidizing conditions.

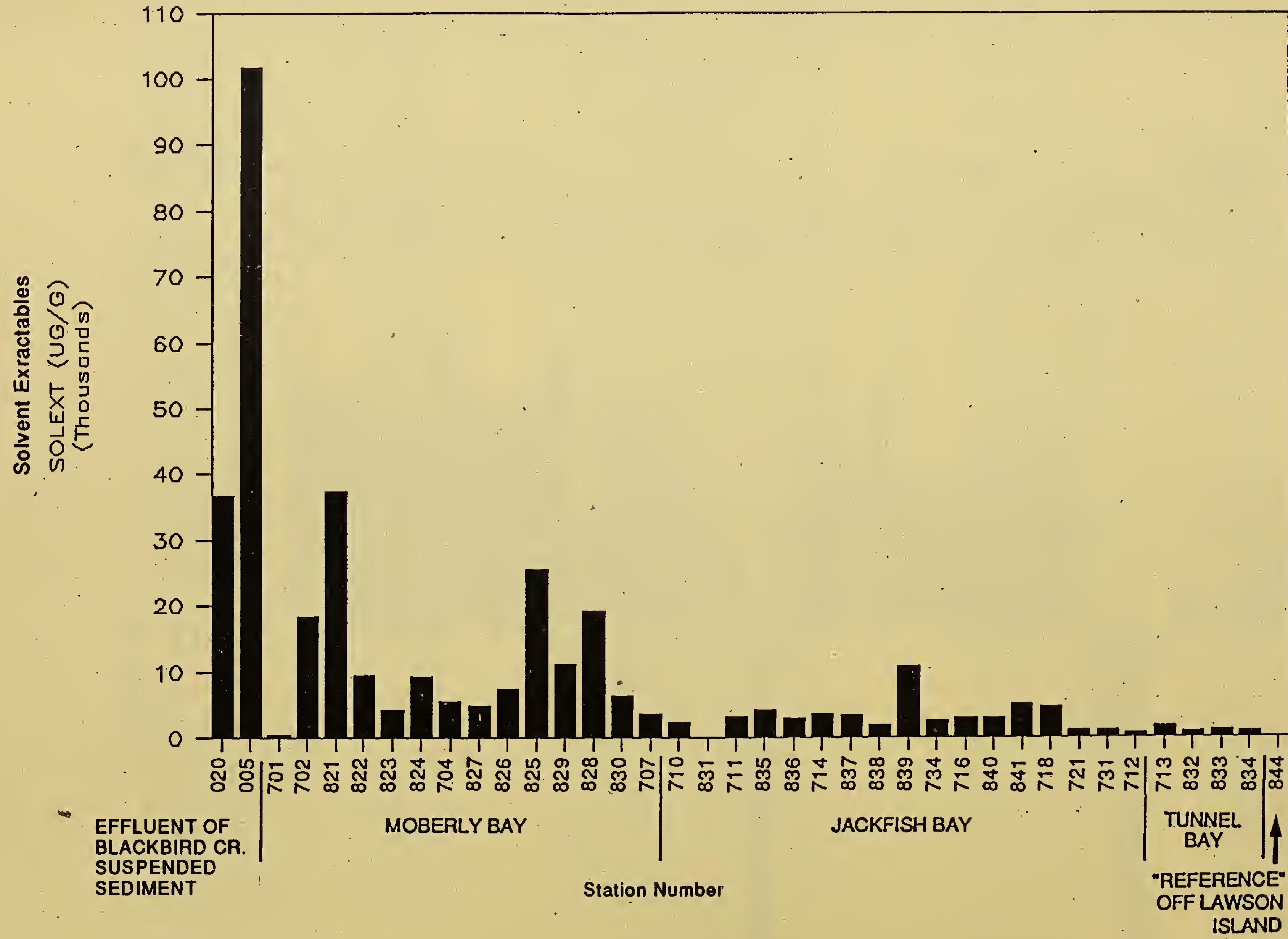


Figure 3.18

Station mean concentrations of oil and grease (solvent extractables) in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

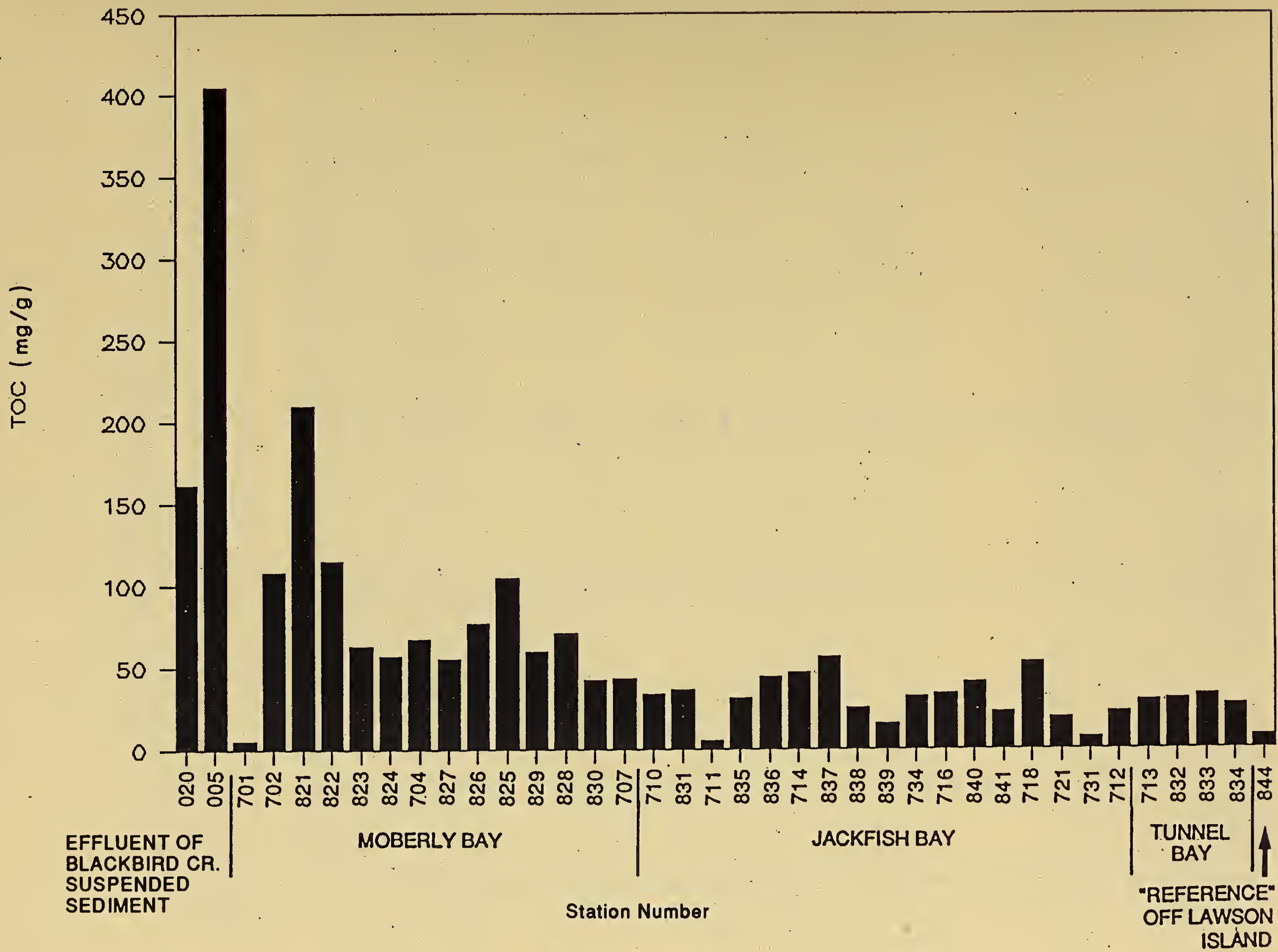


Figure 3.19

Station mean concentrations of total organic carbon (TOC) in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

Table 3.7 Oil and grease and nutrient concentrations in bottom sediments of Jackfish Bay in 1981 (Kirby 1986). Station locations are shown in Figure 3.14.

Station Number		Total Kjeldahl Nitrogen	Total Phosphorous	Oil and Grease
701		200	500	550
702		7,700	1,100	34,600
703		4,300	1,000	-
704		4,300	1,100	11,400
705		300	400	-
706		300	500	-
707		900	900	4,050
708		800	400	-
709		600	600	-
710		2,000	1,000	2,500
711		500	1,100	430
731		1,200	1,000	-
712		1,500	1,300	-
713		1,700	1,200	-
732		300	600	-
714		1,400	1,000	2,100
733		300	1,700	-
734		900	900	-
715		300	600	-
716		2,300	1,000	6,150
718		1,700	1,000	5,200
719		200	800	900
721		300	700	4,500
722		380	1,000	530
PSQG	LEL	550	600	-
	SEL	4,800	2,000	-
OWDG		2,000	1,000	1,500

Note All concentrations mg/kg = ppm
\- not available
PSQG Provincial Sediment Quality Guidelines (Persaud et al. 1991).
LEL - Lowest Effect Level.
SEL - Severe Effect Level.
OWDG OMOE Open Water Dredged Material Disposal Guidelines.

with increasing distance from the mouth of Blackbird Creek (Figure 3.19). This indicates a strong influence of the mill effluent on sediment organic carbon.

Other nutrients which exceeded OWDG or PSQG included total phosphorus and TKN. Total phosphorus exceeded the OWDG (1,000 μg/g) at 45.8 percent of stations and the PSQG-LEL (600 μg/g) at 29.2 percent of stations during 1981 (Table 3.7). The SEL was not exceeded. The range in sample concentrations during 1981 was 400 to 1,700 μg/g with high concentrations ≥1,000 μg/g occurring in all three bays (Table 3.7). During the 1987 surveys the total range of phosphorus in all samples was 300 to 1,580 μg/g (Sherman 1991). The OWDG for TKN is 2,000 μg/g and the PSQG LEL/SEL are 550/4,800 μg/g. The range in sample concentrations during the 1981 surveys was 200 to 7,700 μg/g with the three highest concentrations (>4,000 μg/g) occurring in the bottom sediments of Moberly Bay (Table 3.7). Of a total of 24 stations from the three bays, 4.1 percent exceeded the PSQG-SEL, 20.8 percent exceeded the OWDG, and 58.3 percent exceeded the PSQG-LEL.

3.2.4 Metals

The results of the 1981 survey for heavy metals in bottom sediments are provided in Table 3.8. Kirby (1986) concluded that the sediments were highly contaminated on the basis of the OWDG which were exceeded by individual samples for cadmium (12.5%), chromium (70.8%), copper (45.8%), iron (83.3%), mercury (8.3%) and zinc (16.7%). The PSQG were exceeded at the NEL by these metals as well as by nickel and manganese (Table 3.8). The SEL of the PSQG were exceeded only by manganese (4.2% of samples). Lead was the only metal which did not exceed guidelines. In comparing these results to the results from the 1970 surveys at approximately comparable stations, Kirby (1986) noted that concentrations of mercury, lead and chromium tended to be lower in the more recent survey. Based on a principal components analysis of the 1981 sediment data, he also observed that there was a high correlation of concentration with sediment type (highest concentrations associated with fine-grained sediment) but no distinct trend was discernible for the spatial pattern of sediment concentrations in relation to the mill outfall at the mouth of Blackbird Creek.

The results of the analyses of 10 heavy metals from the 1987 surveys are summarized in Table 3.9 on the basis of effluent and Blackbird Creek mean concentrations (suspended solids), mean concentrations for each depositional basin, and the range of results for all three bays combined. The OWDG and PSQG (LEL and SEL) are also indicated. Figures 3.20 to 3.29 provide individual station mean concentrations for each metal.

The OWDGs were exceeded by the mean concentrations of arsenic, cadmium, chromium, copper, iron, mercury, nickel, and zinc. The PSQG-LEL were exceeded by the same metals as well as by manganese and lead (Table 3.9). The PSQG-SEL was not exceeded by mean concentrations in any of the three depositional basins, however, maximum concentrations of arsenic, mercury and manganese did exceed the Severe Effect Level (Table 3.9). In comparison with the reference station located in Lake Superior (Station 844), background concentrations of chromium, copper, iron and nickel also exceeded their respective PSQG-LELs; manganese concentrations approached the LEL. Because this station is unaffected by any discharges and is considered typical of Lake Superior nearshore sediment for the area, exceedence of the PSQGs and OWDGs are probably due to natural elevated concentrations related to the mineralogy of sediments in the area.

Within Moberly Bay, cadmium, chromium, copper, nickel, mercury and zinc exceeded the LELs. Mercury exceeded the guideline by more than twice the value. The same series of metals with the exception of mercury and zinc also exceeded the LEL in Jackfish and Tunnel Bays. In addition, arsenic, lead and manganese exceeded the LEL in Tunnel Bay. The mean concentration at Station 825 (located near the western shore of Moberly Bay) of 4.69 μg/g exceeded the SEL for mercury.

Table 3.8 Concentration of heavy metals in Jackfish Bay sediments, 1981 (Kirby, 1986). Station locations are shown in Figure 3.14.

Station Number	Cadmium Cd	Chromium Cr	Cobalt Co	Copper Cu	Iron Fe	Lead Pb	Manganese Mn	Mercury Hg	Nickel Ni	Zinc Zn
701	0.3	16	4.7	6	8,600	3	110	0.01	5.5	35
702	0.83	43	5.3	31	9,400	8.7	150	0.17	19	140
703	1.3	66	8.2	49	21,000	17	300	0.55	23	150
704	1.2	6.3	8.3	47	22,000	18	310	0.59	23	140
705	0.3	12	3.5	4.5	9,500	3	86	0.01	5	21
706	0.3	13	3.0	4.8	9,300	3	88	0.01	6	22
707	0.35	36	6.0	16	16,000	5	200	0.07	13	62
708	0.3	20	4.5	8	13,000	3	210	0.01	8.5	32
709	0.3	19	5.0	6.4	15,000	4.8	180	0.01	12	51
710	0.65	45	8.2	32	20,000	15	320	0.14	19	88
711	0.3	26	5.7	9.3	14,000	4.5	280	0.01	12	31
731	0.5	48	9.7	34	23,000	21	770	0.08	22	74
712	0.68	48	9.8	39	26,000	24	1,300	0.10	24	86
713	0.65	40	9.1	41	20,000	27	630	0.11	20	83
732	0.3	26	5.9	9.2	14,000	4	250	0.01	13	35
714	0.7	41	8.6	33	19,000	17	420	0.15	21	77
733	0.23	55	5.9	10	29,000	3.3	280	0.01	13	31
734	0.6	43	8.4	29	19,000	14	330	0.06	19	59
715	0.3	26	5.0	9	15,000	3	250	0.01	14	32
716	1.1	50	8.8	49	21,000	24	460	0.27	24	100
718	0.98	49	7.6	44	21,000	26	470	0.19	22	93
719	0.2	21	3.4	7	10,000	3	230	0.01	12	22
721	0.2	46	8.9	21	23,000	4.1	490	0.01	22	46
722	0.2	37	7.2	16	18,000	5.2	320	0.01	17	42
PSQG LEL	0.6	26	-	16.0	20,000	31	460	0.2	16.0	120
SEL	10.0	110	-	110.0	40,000	250	1,100	2.0	75.0	820
OWDG	1.0	25	-	25.0	10,000	50	-	0.3	25.0	100

Note All concentrations mg/kg = ppm
- not available
PSQG Provincial Sediment Quality Guidelines (Persaud et al. 1991).
LEL - Lowest Effect Level.
SEL - Severe Effect Level.
OWDG OMOE Open Water Dredged Material Disposal Guidelines.

Table 3.9 Mean values ($\mu g/g = ppm$) of heavy metals in three deposition basins in Jackfish Bay surficial sediment, 1987 (Sherman, 1991).

Area		As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
Sample Locations											
KC Effluent (n=2)*		2.20	6.30	315.0	48.5	10550	0.15	890	64.0	16.5	315.0
Blackbird Creek (n=2)*		2.50	16.50	200.0	80.0	9100	0.26	480	36.5	16.0	700.0
Moberly Bay (N=34)		3.10	1.11	56.0	40.0	18579	0.57	248	23.0	17.0	127.0
Jackfish Bay (N=37)		5.10	0.94	53.0	44.0	21972	0.16	431	25.0	26.0	87.0
Tunnel Bay (N=15)		8.40	1.12	58.0	52.0	27800	0.15	755	28.0	37.0	97.0
Range†	Min	0.55	0.20	2.0	4.3	7,900	ND	100	7.0	2.9	29.0
	Max	14.00	2.10	81.0	68.0	31,000	9.10	1,400	31.0	31.0	260.0
PSQG	LEL	6.00	0.60	26.0	16.0	20,000	0.20	460	16.0	31.0	120.0
	SEL	33.00	10.00	110.0	110.0	40,000	2.00	1,100	75.0	250.0	820.0
OWDG		8.0	1.00	25.0	25.0	10,000	0.30	-	25.0	50.0	100.0
Reference											
Station 844 (n=2)		3.30	0.47	48.0 0	29.0 0	22000. 00	<0.01	445. 00	24.0 0	13.0 0	52.0 0

Note All concentrations mg/kg = ppm
- not available
* suspended solids
† based on 102 samples from the three bays.

PSQG Provincial Sediment Quality Guidelines (Persaud et al. 1991).
LEL - Lowest Effect Level.
SEL - Severe Effect Level.
OWDG OMOE Open Water Dredged Material Disposal Guidelines.

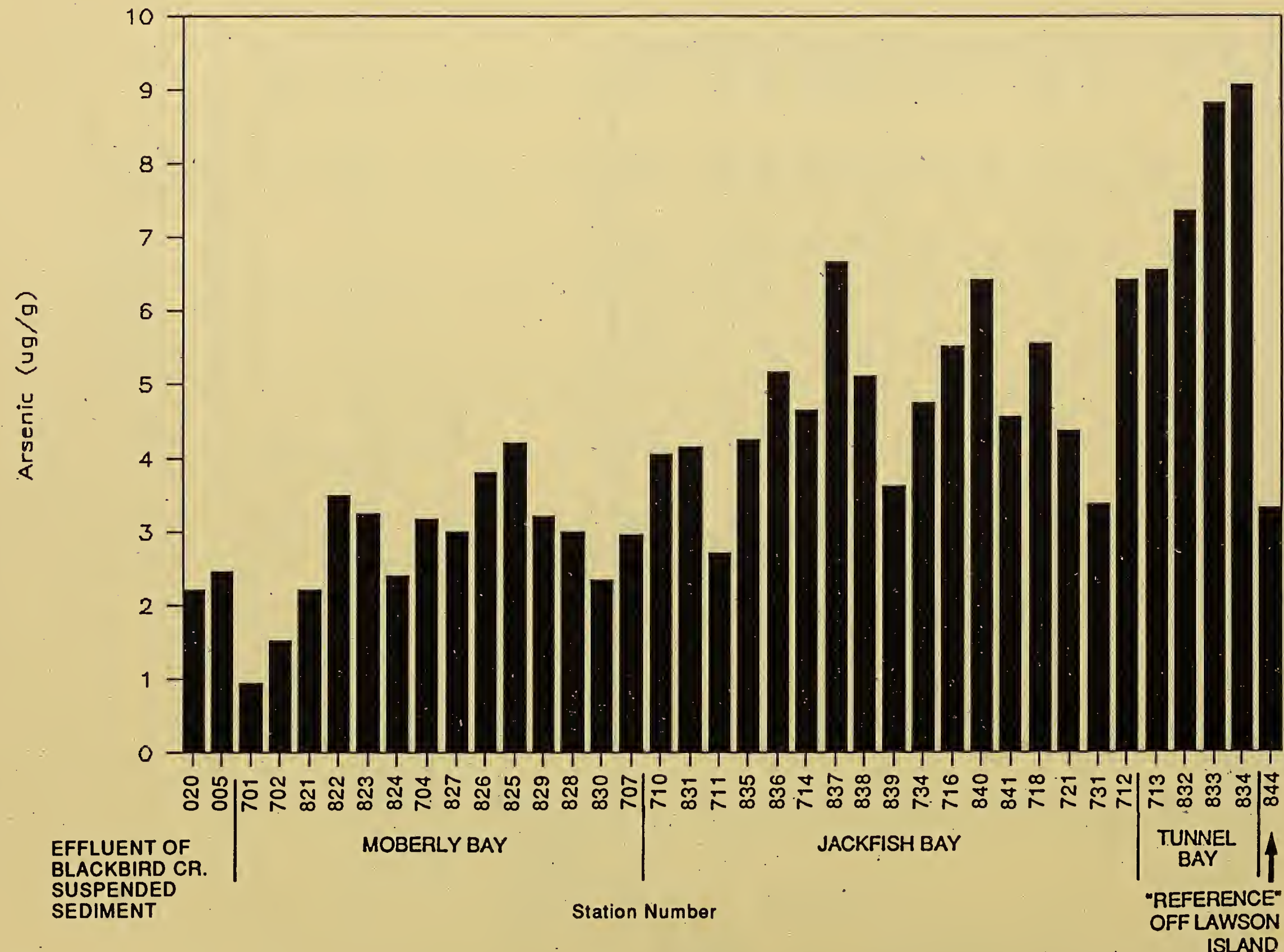


Figure 3.20

Station mean concentrations of arsenic in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

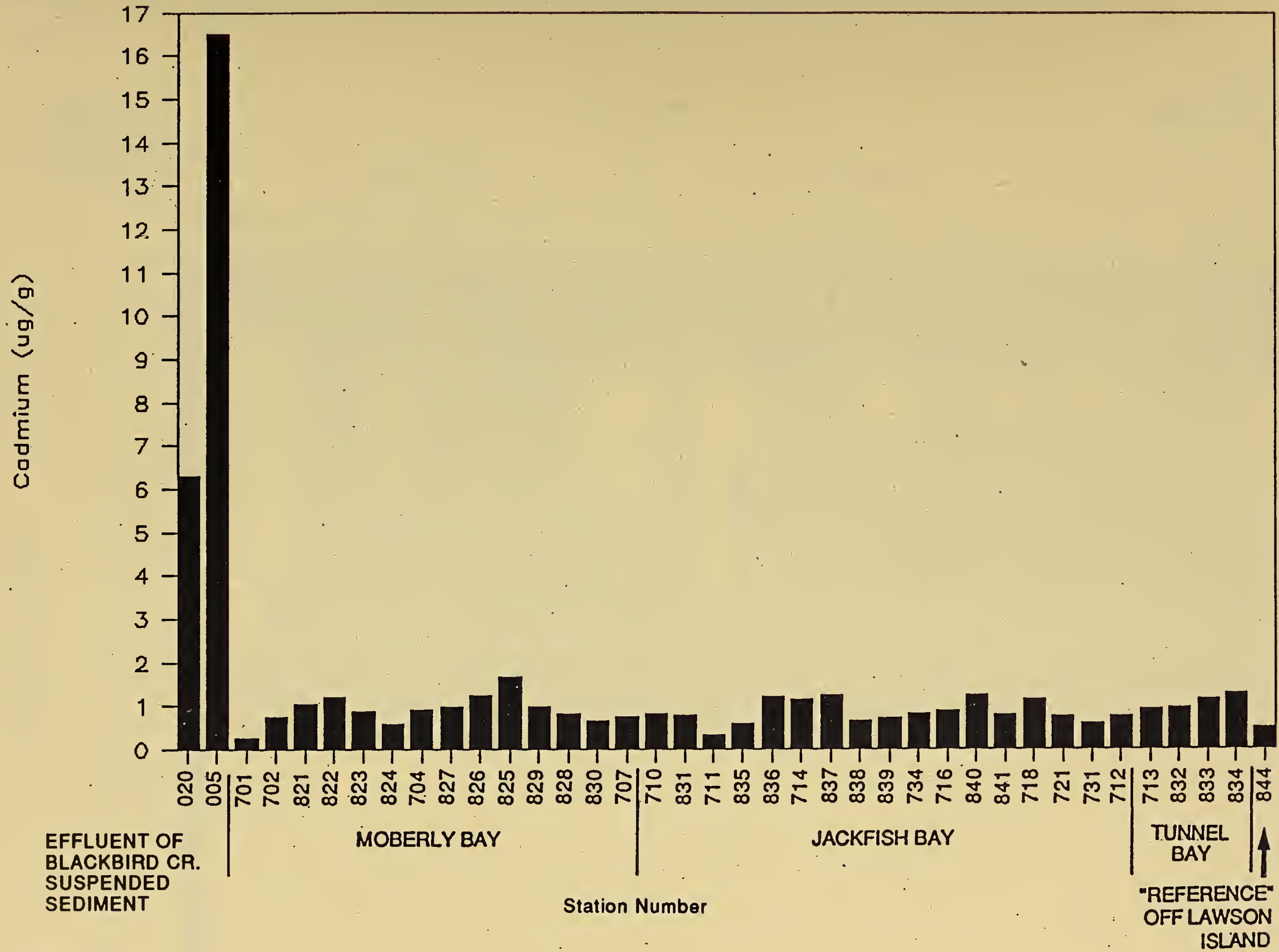


Figure 3.21

Station mean concentrations of cadmium in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

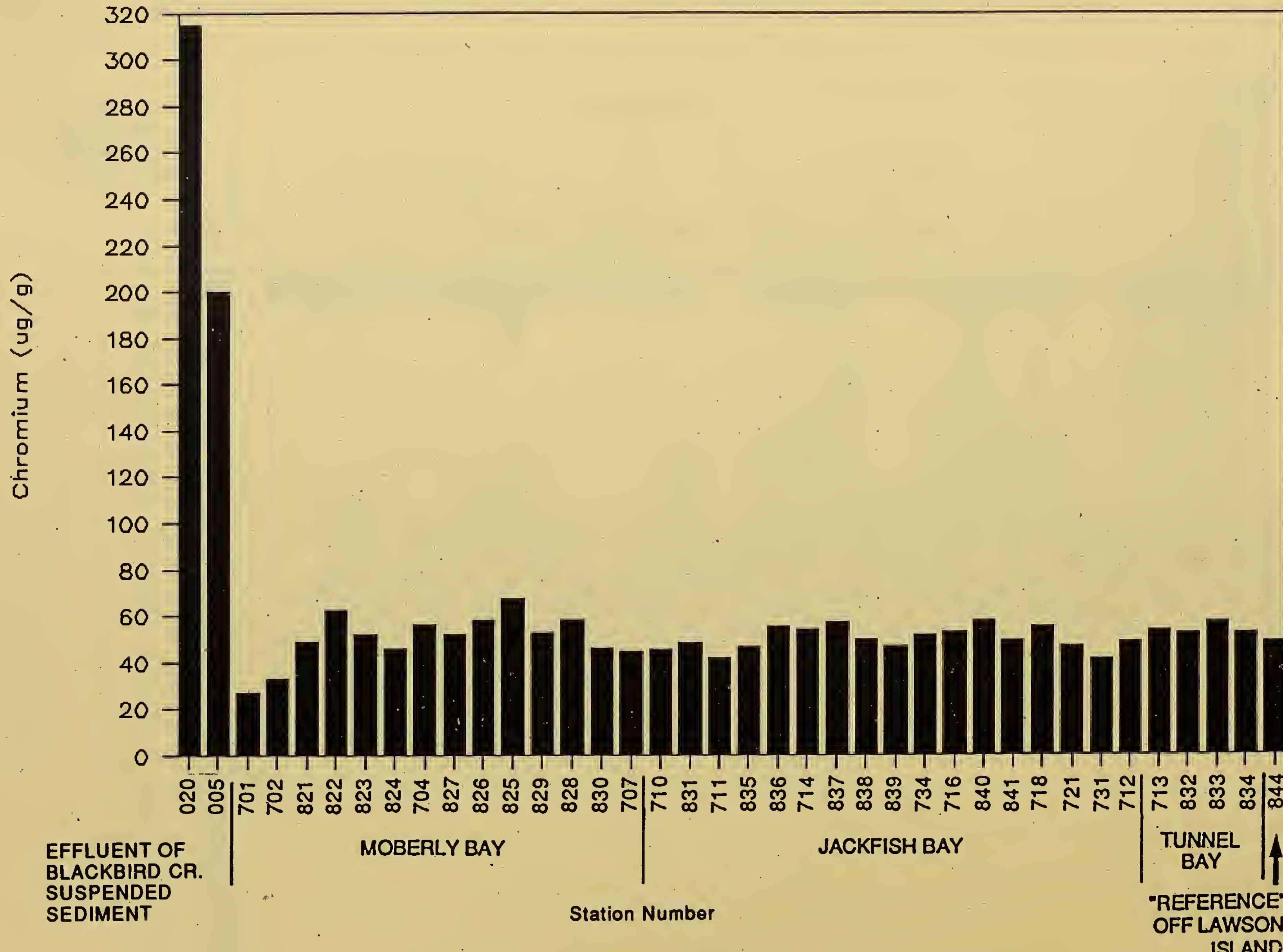


Figure 3.22

Station mean concentration of chromium in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

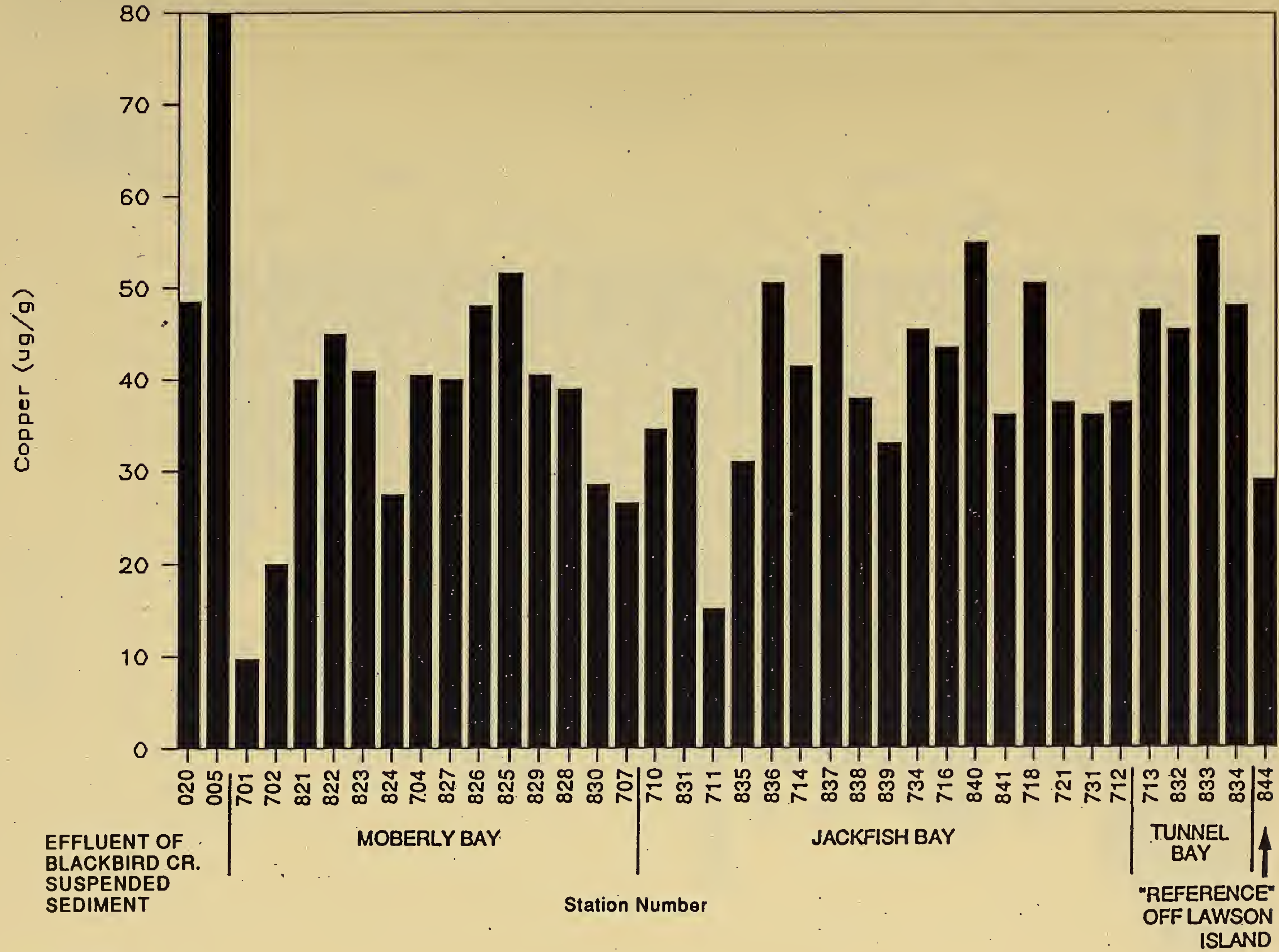


Figure 3.23

Station mean concentrations of copper in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

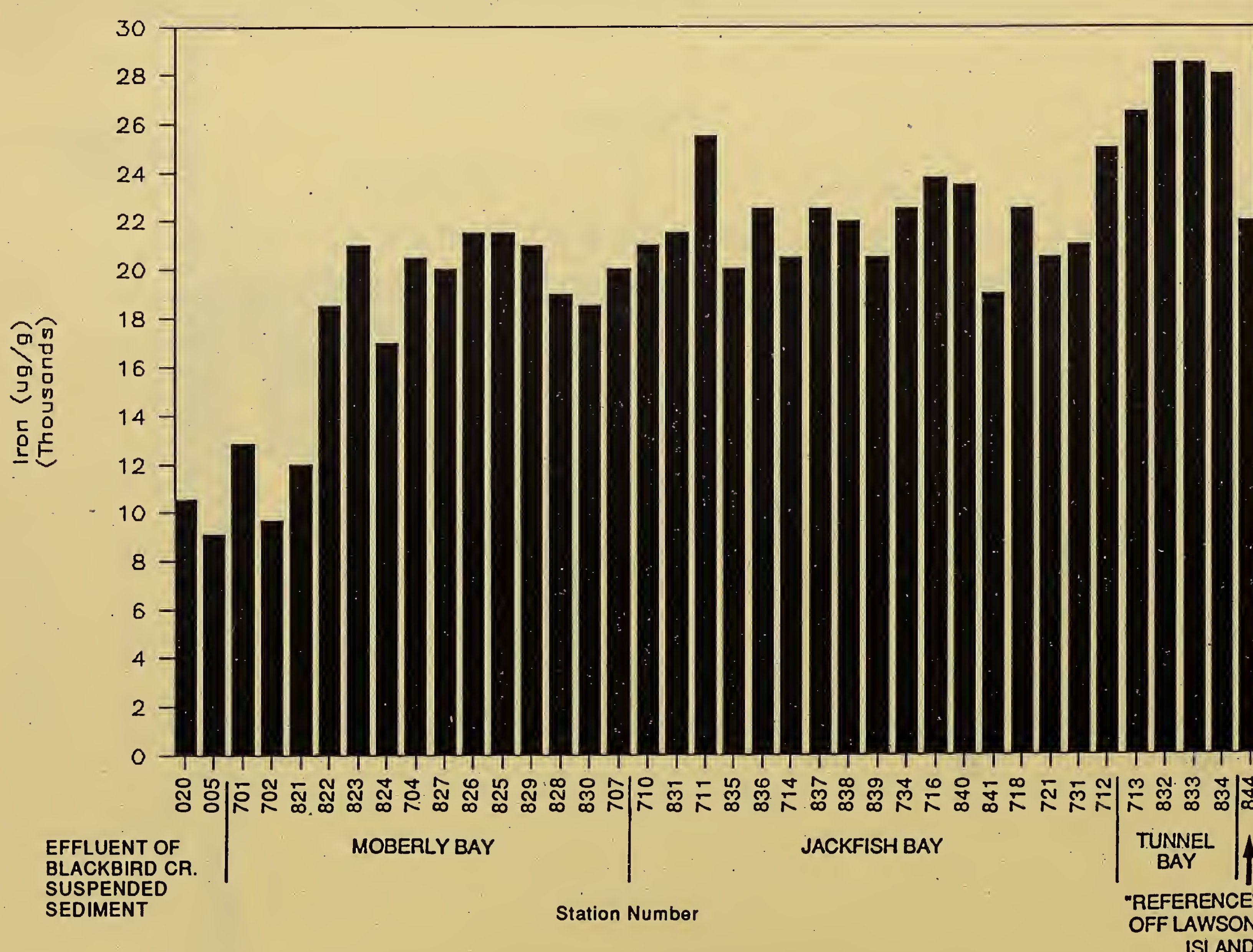


Figure 3.24

Station mean concentrations of iron in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

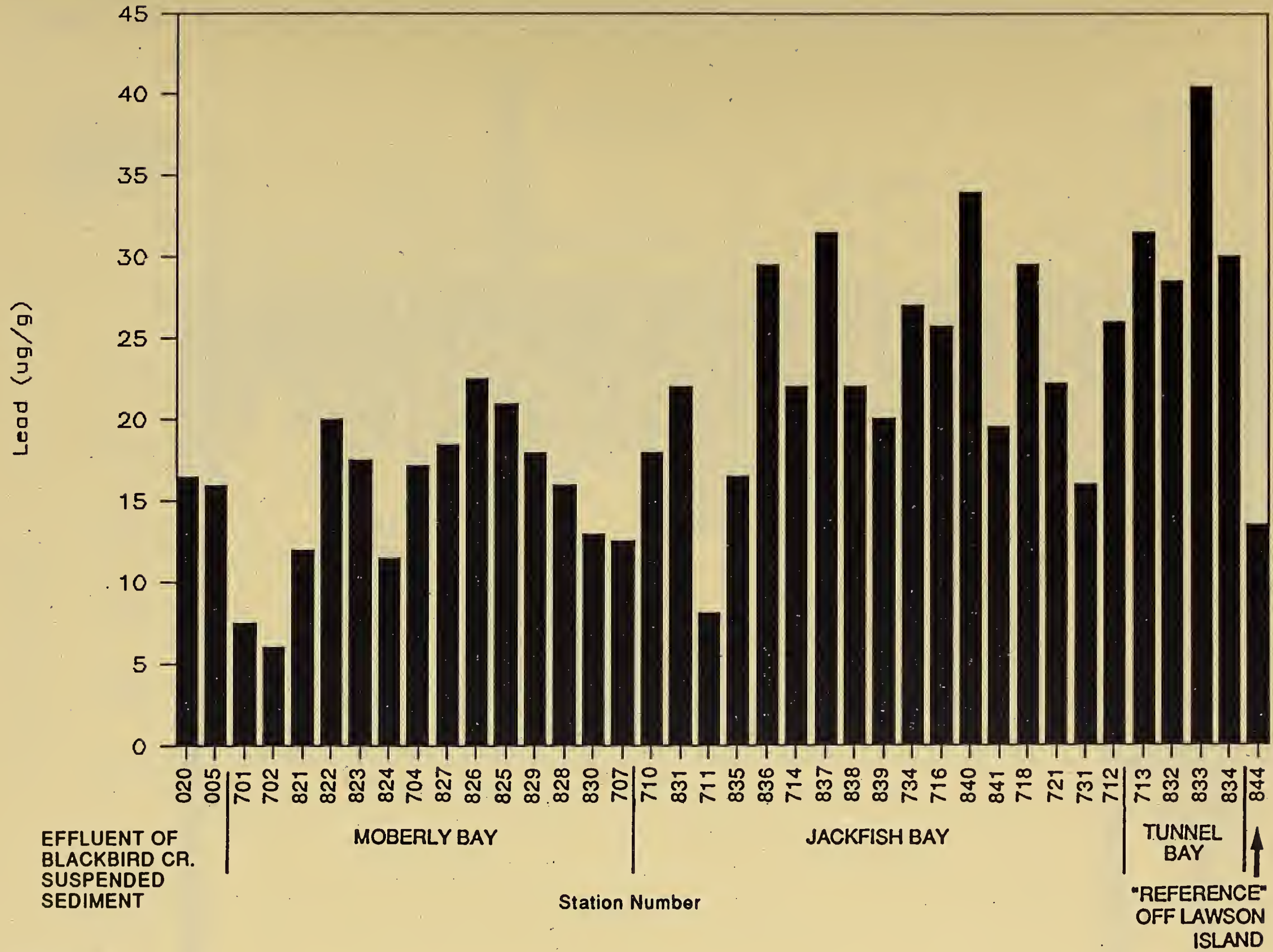


Figure 3.25

Station mean concentrations of lead in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

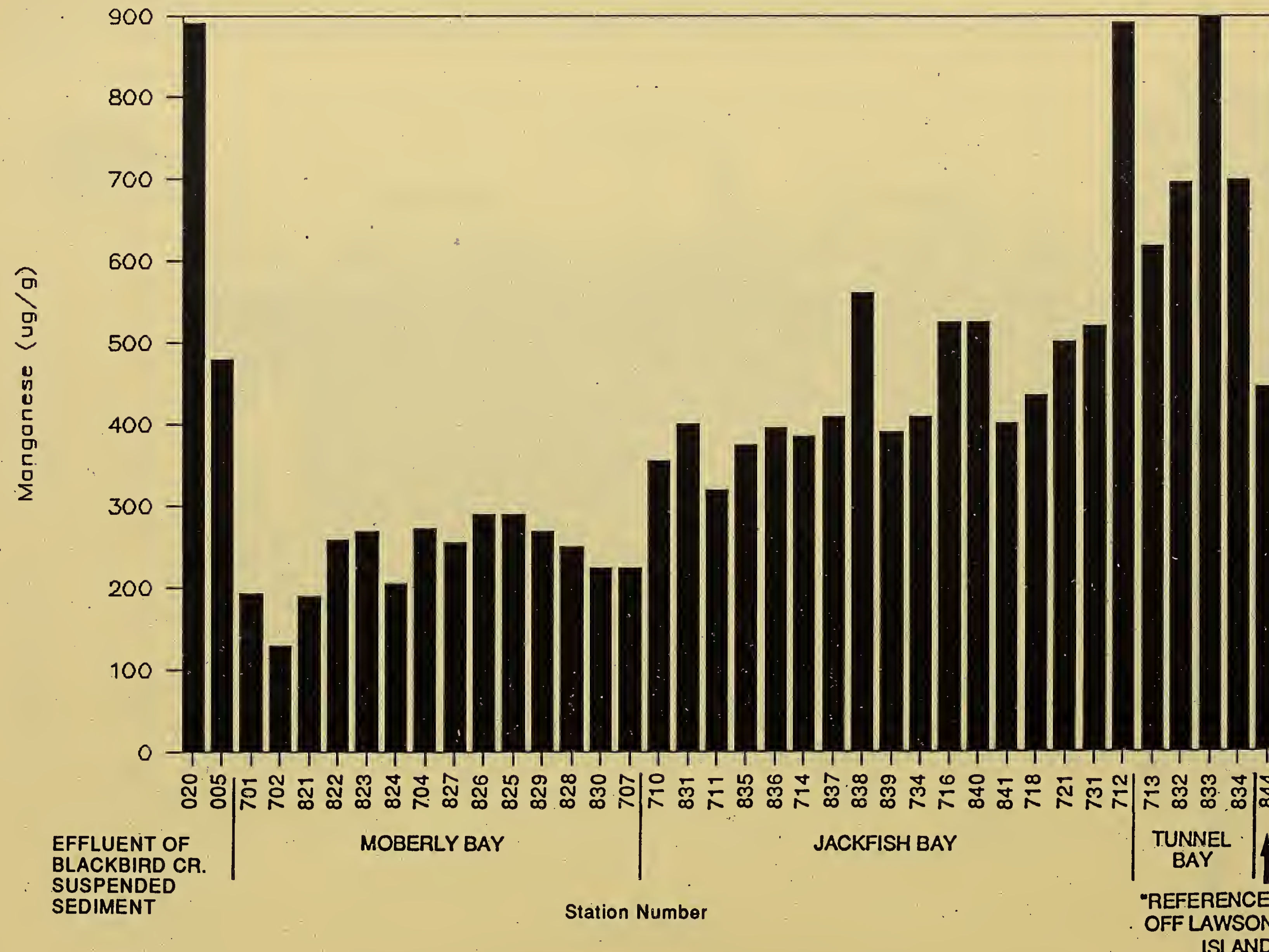


Figure 3.26

Station mean concentrations of manganese In effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

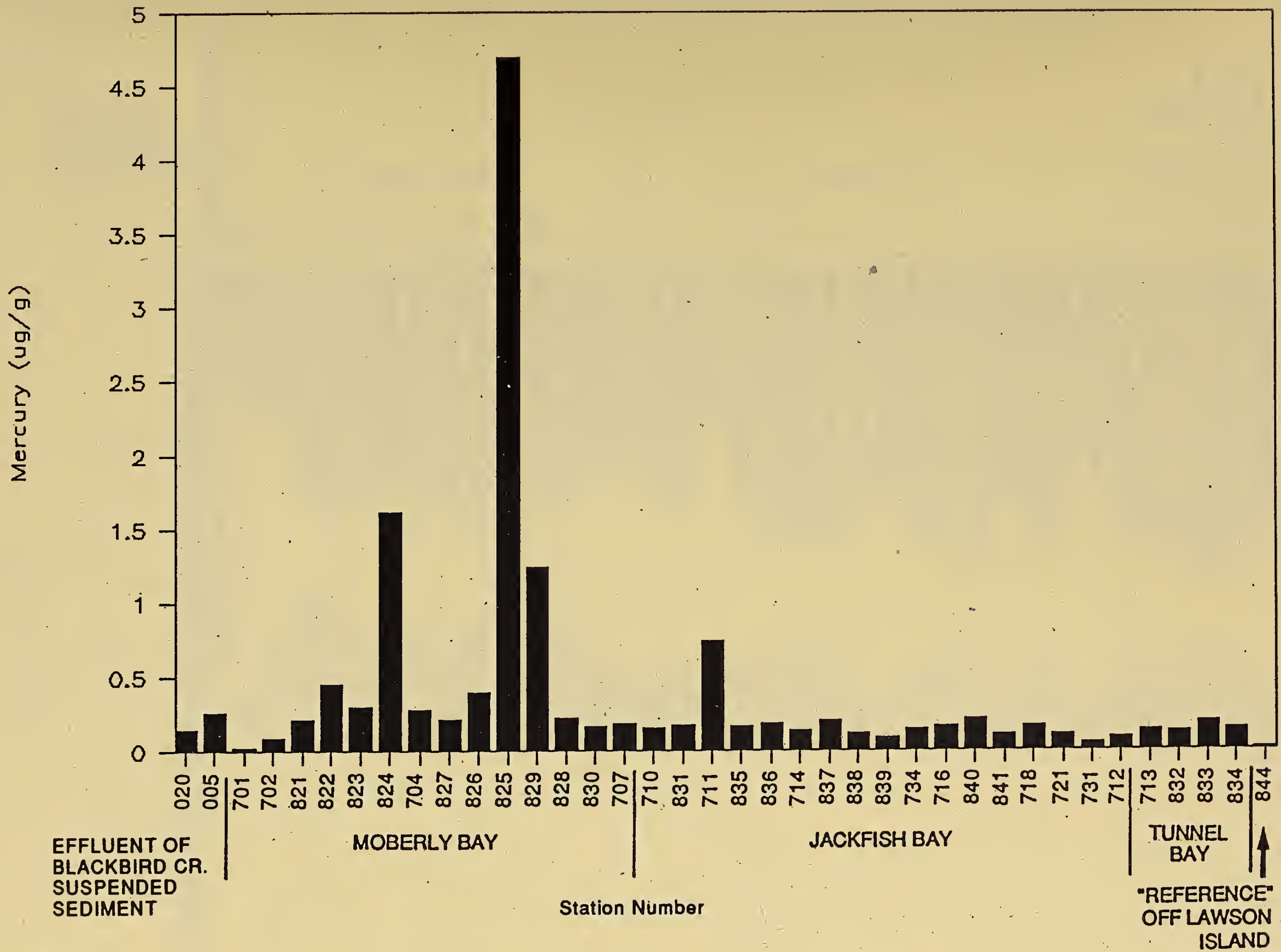


Figure 3.27

Station mean concentrations of mercury in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991) Station locations shown in Figure 3.15.

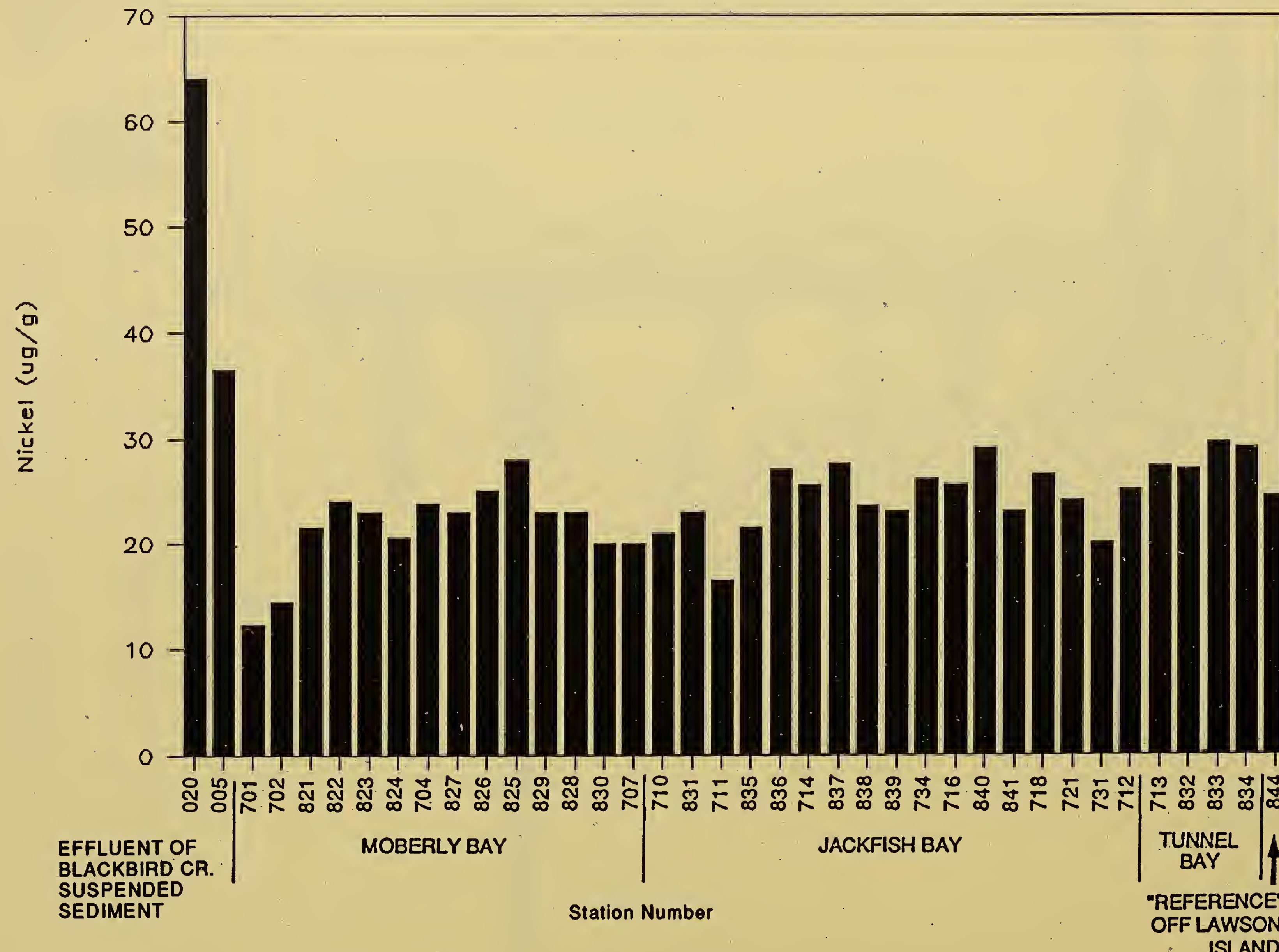


Figure 3.28

Station mean concentrations of nickel in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

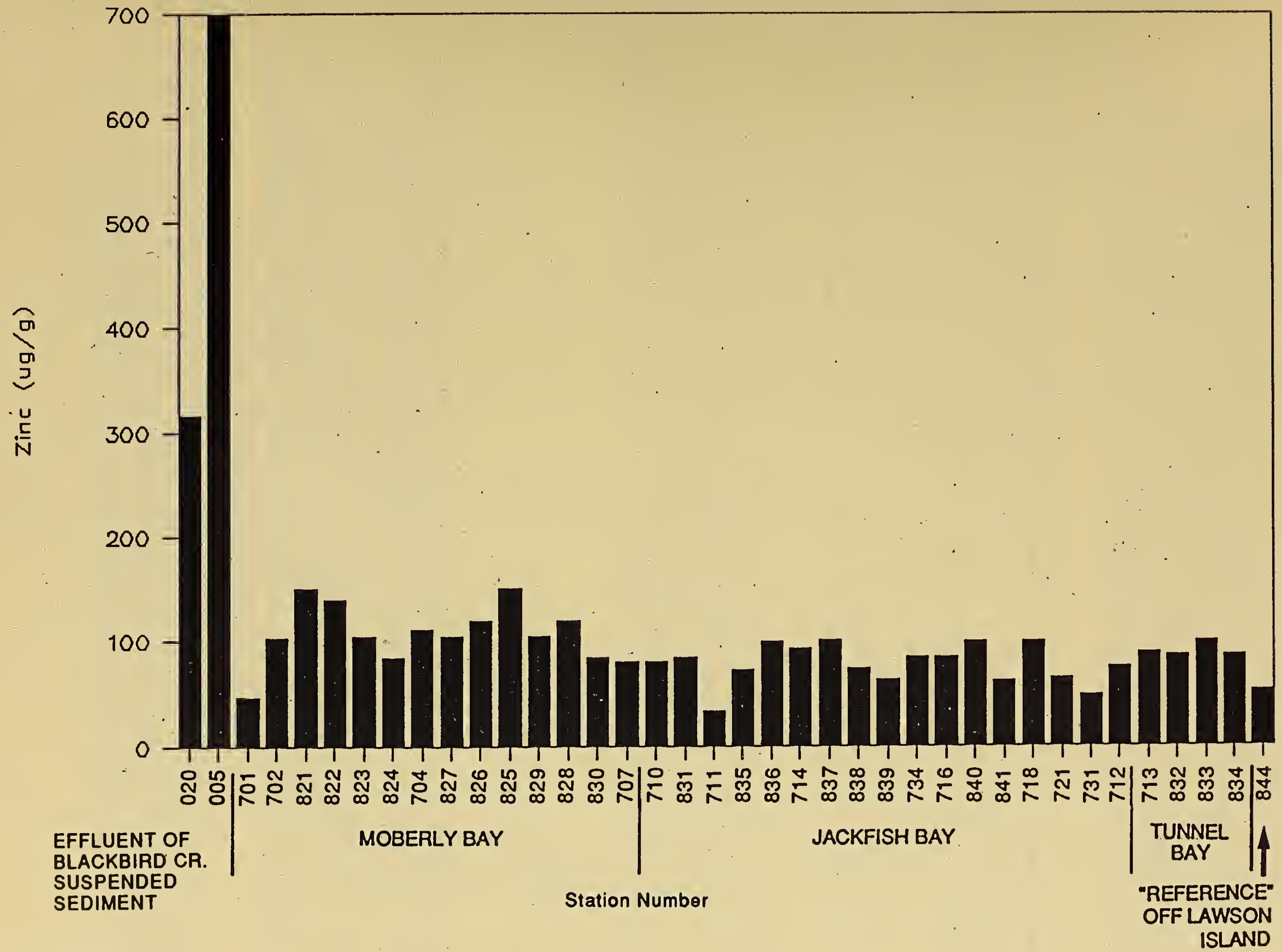


Figure 3.29

Station mean concentrations of zinc in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15.

The results for individual stations were also examined in relation to the mill effluent discharge (Figures 3.20 to 3.29). Generally there is little or no relationship between the mean concentration of most metals and distance from, or concentration in, the mill effluent. Most display little or no relationship (cadmium, chromium, copper and nickel, Figures 3.21-3.23 and 3.28) or a reverse relationship (arsenic, iron, lead and manganese, Figures 3.20, 3.24, 3.25 and 3.26). Only mercury and zinc (Figures 3.27 and 3.29) have concentration patterns which suggest direct impact from the mill effluent. The lack of any trend likely indicates widespread background mineralogy which is confirmed by the absolute concentrations of these five metals at the reference station as noted above. A pattern of increasing concentration at locations furthest from the mouth of Blackbird Creek may reflect transport mechanisms, such as an affinity for finer grain sizes which are carried further, or reflect metal availability.

The movement of metals from sediment to the water column and their availability for biological uptake are important aspects to consider in order to define sources and identify remedial options. The behaviour of some metals such as manganese and iron in the sediments provides some indication of the conditions for sediment/water transfer and the availability of some metals for uptake. Oxides of manganese and iron have a high affinity for other metals. Manganese concentrations are lower in Moberly Bay sediments even though elevated concentrations occur in the suspended sediment in Blackbird Creek and in other areas of the Bay (Figure 3.26). The relatively severe reducing conditions in the Moberly Bay deposition area sediments are likely contributing to the solubilization or stripping of manganese. Similar reductions of iron were noted. The high sorption capacity of manganese and iron oxides for other metals (Forstner and Wittman 1983) may well be providing a mechanism for binding and precipitation of metals in the Blackbird Creek discharge, however, the conditions in Moberly Bay sediments favour release of these metals back into the water column.

The elevated mercury concentrations in Moberly Bay, as compared with other areas (Figure 3.27), can be related directly to the mill effluent. Mercury has historically been used at Kimberly-Clark Canada Inc. and would be expected to be elevated. Zinc also has a pattern of highest concentration in Moberly Bay in relation to the mill effluent discharge, decreasing to lower values in Jackfish and Tunnel Bays (Figure 3.29). However, zinc was not used in the kraft pulp mill process. The sources of this metal in the effluent is not clear although it may be due to the natural presence of zinc in wood fibre, which is then concentrated during the pulping process.

3.2.5 Organics

3.2.5.1 Phenolics and Aromatics

Phenolic compounds are a by-product of the pulping process and would be expected in the effluent discharge (McLeay et al. 1986, OMOE 1988). However, only the higher chlorinated phenolic chemicals would be expected to accumulate in sediments. There are no guidelines for phenolic compounds in sediment.

During the 1981 OMOE surveys, organic contaminants were analyzed at only 13 stations (Kirby 1986). Contaminants included 10 organochlorine pesticides, PCBs, hexachlorobenzene, phenol and guaiacol. Phenol and guaiacol were each detected at 5 of 8 stations during the 1981 surveys (Kirby 1986). The highest concentrations were at stations 702 and 704 as in the case of PCBs. Phenol concentrations ranged from not detected to 9.98 μg/g and guaiacol ranged from not detected to 16.5 μg/g (Kirby 1986).

Organochlorines, including 20 phenolic compounds, 12 chlorinated benzenes and 1 volatile, were measured in sediment samples during the 1987 and 1988 surveys (Sherman 1991). Detectable concentrations were found for only six parameters including hexachlorobenzene, pentachlorobenzene, tetrachlorobenzene, pentachlorophenol, tetrachlorophenol and 2,4,6-trichlorophenol. The results are summarized in Table 3.10. There are no guidelines for any of these compounds with the exception of hexachlorobenzene.

Table 3.10 Frequency of detection and maximum concentration of organochlorine compounds in surficial sediments in the three depositional areas of the Jackfish Bay AOC during 1987/88 (Sherman 1991).

	Detection limit	Moberly Bay Station 15, N=41	Jackfish Bay Station 18, N=46	Tunnel Bay Station 4, N=18
		% (Max)	% (Max)	%
Hexachlorobutadiene	1	0	0	0
Hexachlorobenzene	1	83 (32)	17(3)	0
Hexachloroethane	1	0	0	0
Pentachlorobenzene	1	12 (3)	0	0
2,3,6-trichlorotoluene	1	0	0	0
2,4,5-trichlorotoluene	1	0	0	0
2,6 a-trichlorotoluene	1	0	0	0
1,2,3 trichlorobenzene	2	0	0	0
1,2,3,4 tetrachlorobenzene	1	2 (4)	0	0
1,2,2,3,5 tetrachlorobenzene	1	0	0	0
2,1,2,4,5 tetrachlorobenzene	1	0	0	0
1,3,5 tetrachlorobenzene	2	0	0	0
Pentachlorophenol	50	5 (880)	0	0
2,3,4 trichlorophenol	100	0	0	0
2,3,4,5, tetrachlorophenol	50	2 (128)	0	0
2,3,5,6 tetrachlorophenol	50	0	0	0
2,4,5 trichlorophenol	50	0	0	0
2,4,6 trichlorophenol	50	5 (302)	2*	0

Note All concentrations in $\mu g/g$ = ppm
* N=2

Volatiles and chlorinated benzenes have been associated with pulp mill effluents. Hexachlorobenzene was detected in 83 percent of the samples collected in Moberly Bay; the maximum value detected was 0.032 $\mu g/g$. The Lowest Effect Level (PSQG) for this parameter is 0.01 $\mu g/g$ and this level was exceeded by the maximum value measured in Moberly Bay (Table 3.10). Traces of penta- and 1,2,3,4-tetrachlorobenzene were also noted.

Measurable concentrations of three chlorophenolic chemicals were also detected in Moberly Bay. 2,4,6-trichlorophenol was also detected at one station just outside Moberly Bay in the Jackfish Bay deposition area (Table 3.10).

3.2.5.2 Resin and Fatty Acids

The highest concentrations and frequency of detection of resin and fatty acids during the 1987 and 1988 surveys were in Moberly Bay (Table 3.11). Even though resin acids are reported to rapidly degrade (Taylor et al. 1988), high concentrations of several resin and fatty acids were found in sediments of all three depositional basins in the Jackfish Bay AOC. Dichlorodehydroabietic acid, which is one of the more persistent resin acids, was found in more than half of the samples from Moberly Bay (maximum concentration 3,700 ug/g). Elevated concentrations of dehydroabietic acid and other resin acids in Moberly Bay, as well as in Tunnel Bay, suggest that resin acids are more widely distributed and do not break down as quickly as expected in the aquatic environment.

3.2.5.3 Dioxins and Furans

Dioxins and furans include 75 isomers of polychlorinated dioxins and 135 isomers of polychlorinated furans. The most toxic forms are those substituted at the 2,3,7,8 positions, particularly 2,3,7,8-tetrachlorodibenzo-p-dioxin. The toxic effects of dioxins and furans include weight loss, thymic atrophy, immunotoxicity, hepatotoxicity and porphyria, chloracne, hyperplasia and cancer, teratogenicity and reproductive toxicity (Safe 1990).

Dioxins and furans are by-products formed in combustion reactions, such as forest fires, and incinerators, as a result of the manufacture of industrial chemicals, and from the chlorination (bleaching) stage of bleached kraft pulp mills. Concentrations of 2,3,7,8-substituted dioxins and furans are usually undetectable in the ambient environment. Background levels of other isomers can often be detected, due to aerial deposition from industrial sources and/or diffuse production in forest fires, principally of the highly chlorinated forms (hepta and octa) which are very stable in sunlight and tend to persist in the environment. Industrial discharges of dioxins and furans to the air and water result in a net localized loading of these chemicals which adsorb to organic sediments and soils and which are adsorbed by aquatic or terrestrial animals from their diet. These chemicals can bioaccumulate to toxic levels in higher organisms.

Both bleached kraft mills and mills which do not use bleaching have been identified as sources of many forms of dioxins, but principally furans (OMOE 1988a). In both cases many of the isomers detected are the almost ubiquitous highly chlorinated forms found throughout the environment. However, mills using bleaching often discharge the 2,3,7,8-substituted forms.

Because dioxins and furans are poorly water soluble, they precipitate with suspended solids to the bottom sediments of the receiving environment. Little data exist, however, for concentrations of dioxins and furans in sediments (Sherman et al. 1990), and a guideline for these chemicals in sediment has not been established.

During the 1987 and 1988 surveys, sediment and effluent samples from Jackfish Bay were analyzed for polychlorinated dibenzo-p-dioxins (CDDs) and dibenzofurans (CDFs). Sediments from the middle of

Table 3.11 Frequency of detection and maximum concentrations ($\mu g/g$) of resin and fatty acids in surficial sediments in the three depositional areas of the Jackfish Bay AOC during 1987/88 (Sherman 1991).

Resins and Fatty Acids	Minimum Value ($\mu g/g$)	Moberly Bay sta=8, n=33		Tunnel Bay sta=4, n=12		Jackfish Bay sta=5, n=32	
		%	max $\mu g/g$	%	max $\mu g/g$	%	max $\mu g/g$
capric acid	70	36	470	8	195	0	
phthalic acid	24	15	132	0		0	
lauric acid	25	33	455	25	510	12	1020
myristic acid	7	84	2125	83	840	65	2635
palmitic acid	50	69	7470	41	3175	59	12810
linoleic acid	128	12	2255	16	545	12	1705
linolenic acid	57	84	6515	33	330	46	1515
oleic acid	10	81	2030	5	3690	34	3600
stearic acid	10	45	2720	25	910	21	3650
pimaric acid	205	21	1065	0		3	245
sandaracopimaric acid	445	3	700	16	660	0	
isopimaric acid	145	63	3605	8	1535	3	1245
palustric acid	800	3	800	0		0	
dehydroabietic acid	105	94	13110	100	10385	71	5250
arachidic acid	75	84	4990	100	1295	68	3605
abietic acid	51	93	4304	50	1195	50	1390
neoabietic acid	50	15	1035	0		0	
dichlorostearic acid	45	27	680	0		3	130
chlorodehydroabietic acid	95	48	1440	8	95	9	1125
dichlorodehydroabietic acid	108	66	3700	0		9	2100

Moberly Bay (Station 704) showed moderate concentrations of tetrachlorodibenzofurans (4CDF) and octachlorodibenzo-p-dioxins (8CDD) with trace concentrations of other dioxin and furan congeners (Table 3.12).

A difference test (MANOVA with Student-Neumen-Kuels test), between log transformed suspended solids and surficial sediment values, was carried out to determine whether the suspected point source was responsible for elevated contaminant levels (Sherman et al. 1990). Results for a difference test carried out for 4CDF and 8CDD (Table 3.12) were different for the two congeners. There was a progression of significant differences from the effluent to the sampled stations for 4CDF mean values. This suggests that the effluent was the main source of this congener. In contrast, there were no significant differences between the stations for 8CDD within Jackfish Bay, indicating that the mill was not the source. Some other source, such as atmospheric deposition, may have been responsible for elevated 8CDD levels.

Table 3.12 Octachlorodibenzo-p-dioxins (8CDD) and tetrachlorodibenzofurans (4CDF) (pg/g d.w.) found in surficial sediment samples from Jackfish Bay and suspended solids from the effluent and Blackbird Creek during 1987/88 (Sherman et al. 1990). Station locations are shown in Figure 3.15).

	Stations							Manova Values		
	5	20	704	716	713	844	845	F value	P value	r^2
Number of Samples	2	2	4	2	4	2	2			
8CDD (pg/g)	250	141	219	233	126	32	12	13029	0.0002	0.88
4CDF (pg/g)	6223	2000	411	139	31	11	2.4	21.83	0.0001	0.92

(Sediment values represent geometric means. Also shown are results of a multivariate analysis of variance and student-Newman-Keuls test of between station differences. Statistically similar stations are joined with a double line.)

Figure 3.30 represents the sediment core profile for dioxin and furan congeners found in Moberly Bay at station 704. As with the surficial sediments, 4CDF and 8CDD congeners were the most common at all depths where detectable concentrations occurred. Low concentrations of 7CDD, 5CDF and 7CDF congeners were also detectable.

The congener pattern for the higher chlorinated congeners was similar to the "combustion pattern" found by Czuczwa and Hites (1986) in Siskiwit Lake (Isle Royale, Lake Superior). This combustion pattern is a typical background pattern for Lake Superior. A similarity between Jackfish Bay and Siskiwit Lake patterns indicates that the mill is not the source for these congeners; contamination is probably due to atmospheric sources. However, a pattern dominated by 4CDF from the pulp mill effluent was superimposed on this combustion pattern, indicating that 4CDF stems from the mill effluent.

3.2.5.4 Other Organics

The 1981 OMOE surveys found concentrations of organochlorine pesticides and hexachlorobenzene to be generally not detectable or detected in only trace amounts (Kirby 1986). Total PCB concentrations, however, ranged from not detected to 0.930 $\mu g/g$ at 12 stations. The highest concentrations occurred at stations 702 (0.930 $\mu g/g$) and 704 (0.485 $\mu g/g$) in Moberly Bay. Detectable concentrations were found at 8 stations of which the OMOE Open Water Dredged Material Disposal Guidelines (0.05 $\mu g/g$) was exceeded at 7 stations. The PSQG-LEL for total PCBs (0.07 $\mu g/g$) was exceeded at 6 stations.

The results for 29 organochlorines including pesticides, octachlorostyrene and PCBs measured during the 1987 and 1988 surveys are summarized in Table 3.13 according to depositional basin. Detectable concentrations were limited to the sediments collected from Moberly Bay with the exception of γ-BHC, octachlorostyrene, DDE, pp-DDD, 2,4-dichlorophenoxybutyric acid and 2,4-propionic acid (Table 3.13). The source of these compounds in the effluent is unknown.

PCBs were measured in samples from Moberly Bay (Table 3.13 and Figure 3.31). The maximum concentration of total PCBs is 0.280 $\mu g/g$ (280 ng/g) which exceeds the OWDG of 0.05 $\mu g/g$ and the PSQG-LEL of 0.07 $\mu g/g$. Their presence may relate to past uses of PCBs in industrial electrical equipment at the mill.

Polynuclear aromatic hydrocarbons (PAHs) were evenly distributed at low concentrations throughout the study area. The tentative PSQG for total PAHs is 2.0 $\mu g/g$. This was not exceeded by the total of the 16 PAHs measured at any station (Table 3.14). The concentration pattern and frequency of occurrence is fairly uniform throughout the three depositional basins and, hence, do not appear to be influenced by the mill effluent (Table 3.14). As in the case for the higher chlorinated dioxin congeners, atmospheric deposition may be the most likely source of the PAH compounds. They are known to be created by low temperature burning such as from wood stoves (Chan and Perkins 1989).

3.2.6 Historical Changes in Sediment Quality

Through radiodating techniques (Sherman et al. 1990), it is possible to determine the age of horizontal sections of a sediment core sample. Once these dates are established and contaminant levels in the sections are determined, contaminant levels can be compared to mill activities, such as process changes or leaks and spills, which may have resulted in sediment contamination. Radiodating is a useful means of understanding the historical context of environmental impact related to ongoing industrial activity.

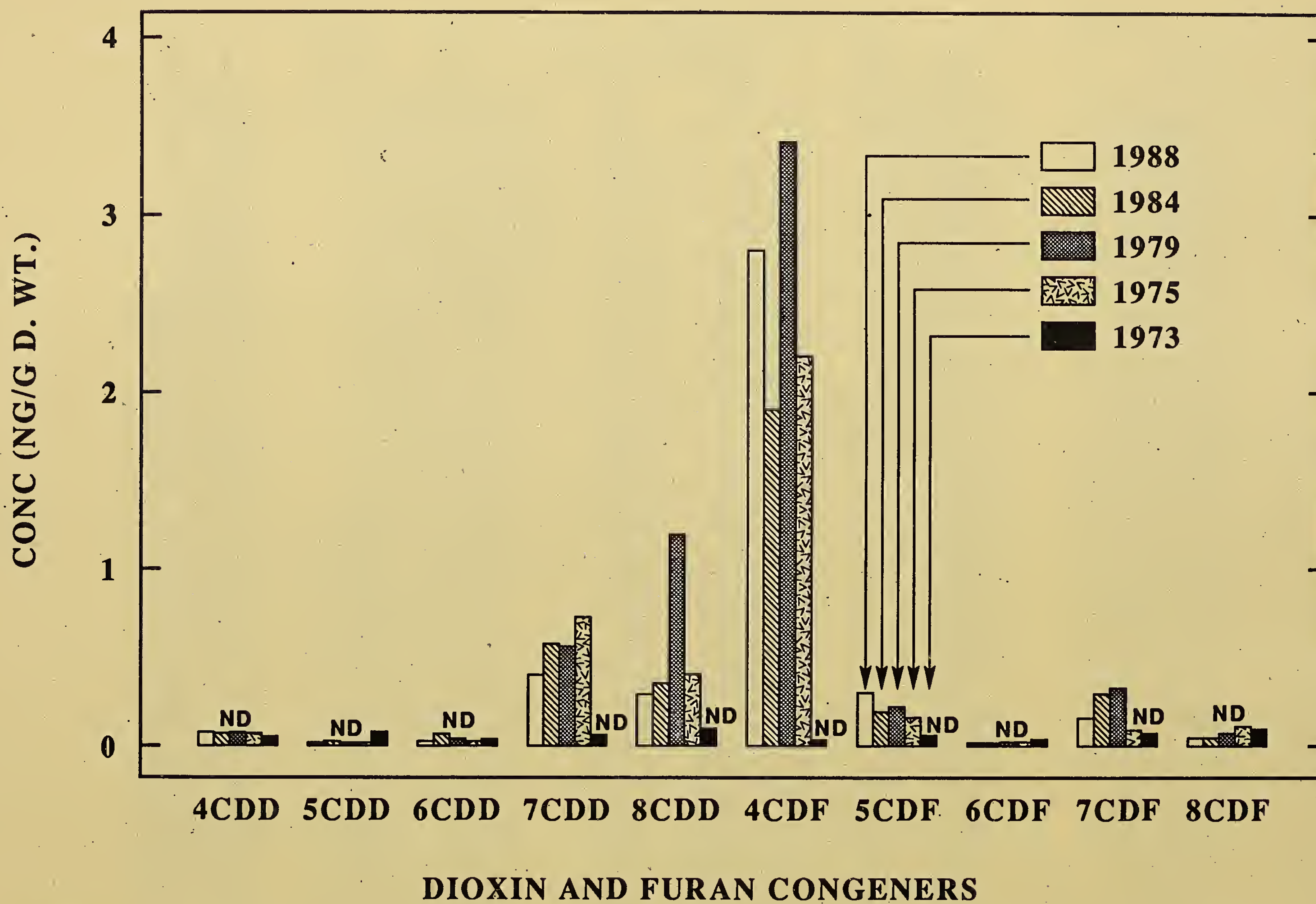


Figure 3.30

Sediment core profile of dioxin furan congeners at Station 704 in Moberly Bay collected during 1988 (Sherman 1991). Station location shown in Figure 3.15.

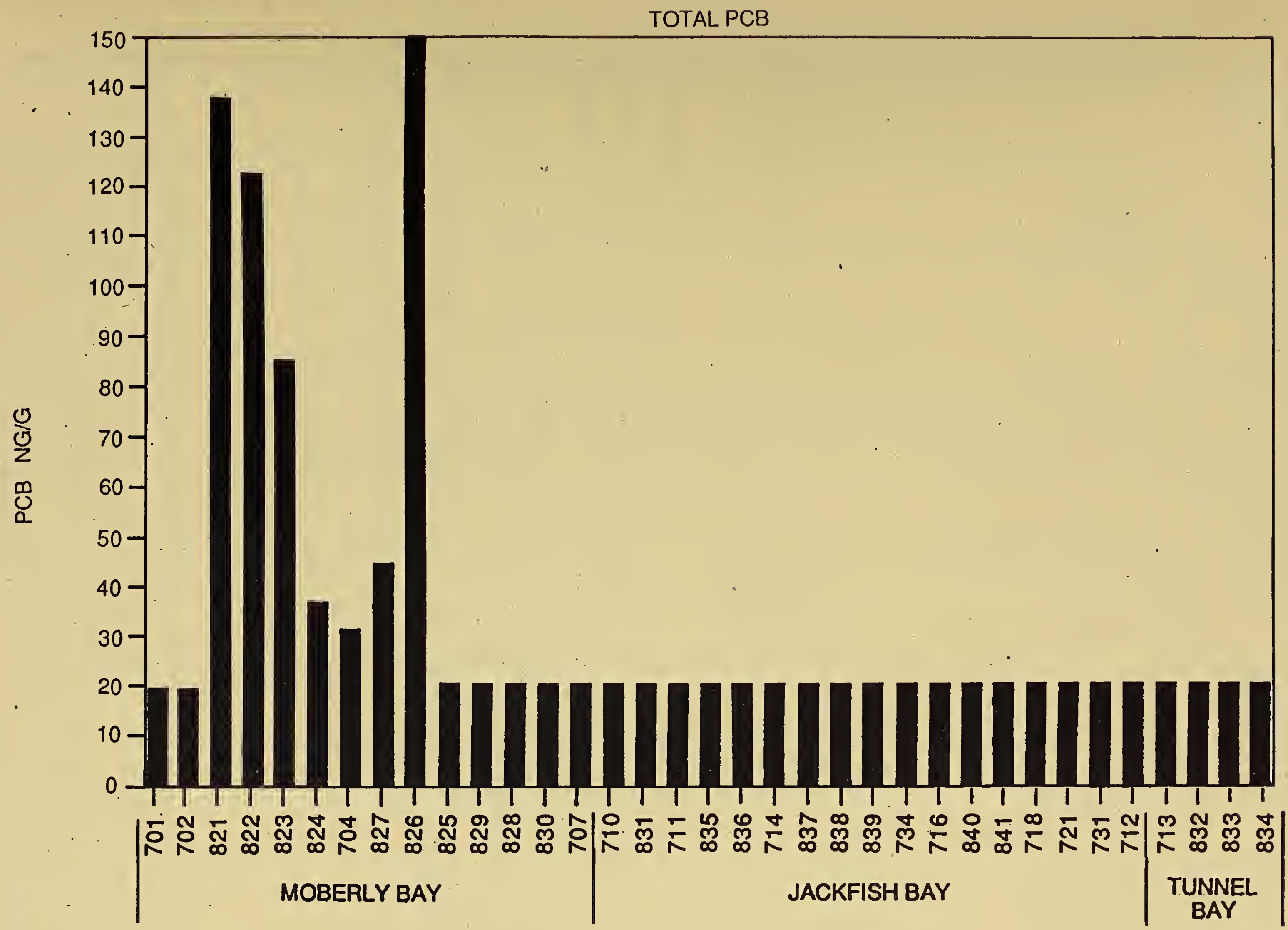


Figure 3.31

Station mean concentrations of total PCBs (ng/g) in effluent (suspended solids) and in the three depositional basins (surficial sediment) for the Jackfish Bay AOC during 1987/88 (Sherman 1991). Station locations shown in Figure 3.15. Detection limit is 20 ng/g.

Table 3.13 Frequency of detection and maximum concentration (ng/g) of organochlorine compounds in surficial sediments in the three depositional areas of the Jackfish Bay AOC during 1987/88 (Sherman 1991).

Compound	Detection Limit (ng/g)	Moberly Bay sta=15,n=37		Jackfish Bay sta=18,n=45		Tunnel Bay sta=4,n=18	
		%	max ng/g	%	max ng/g	%	max ng/g
Aldrin	1	0		0		0	
Hexachlorocyclohexane (α-BHC)	1	11	3	0		0	
Hexachlorocyclohexane (b-BHC)	1	22	6	0		0	
Hexachlorocyclohexane (γ-BHC)	1	76	32	20	29	6	4
α-Chlordane	2	35	15	0		0	
γ-Chlordane	2	22	9	0		0	
Dieldrin	2	0		0		0	
Methoxychlor	3	0		0		0	
Endrin	4	0		0		0	
Endosulfan sulphate	4	0		0		0	
Endosulfan I	2	0		0		0	
Endosulfan II	4	0		0		0	
Heptachlor epoxide	1	0		0		0	
Heptachlor	1	0		0		0	
Mirex	5	0		0		0	
Oxychlordane	2	0		0		0	
Octachlorostyrene	1	65	18	4	2	0	
op-DDT	5	11	15	0		0	
Polychlorinated biphenyls	20	19	280	0		0	
DDD	5	11	15	0		0	
DDE	1	24	18	11	5	11	10
PP-DDD	5	68	45	17	10	0	
Dicamba	100	0		0		0	
Picloram	100	11	440	0		0	
Silvex	50	0		0		0	
24-Dichlorophenoxyacetic acid	100	0		0		0	
24-Dichlorophenoxybutyric acid	200	0		2	275	0	
24-D Propionic acid	100	8	155	4	110	0	
245-Trichlorophenoxyacetic acid	50	0		0		0	

Table 3.14 Frequency of detection and maximum concentration ($\mu g/g$) of polynuclear aromatic hydrocarbons in surficial sediments in the three depositional areas of the Jackfish Bay AOC during 1987/88 (Sherman 1991).

Compound	Detection limit ($\mu g/g$)	Moberly Bay sta=15,n=10		Jackfish Bay sta=5,n=10		Tunnel Bay sta=4,n=5	
		%	max $\mu g/g$	%	max $\mu g/g$	%	max $\mu g/g$
Dibenzo (a,h) anthracene	0.04	29	0.06	10	0.04	0	
Benzo (g,h,i) perylene	0.04	53	0.09	40	0.06	50	0.09
Naphthalene	0.04	0		20	0.09	50	0.16
Acenaphthylene	0.04	0		0		0	
Acenaphthene	0.04	0		0		0	
Fluorene	0.04	0		0		0	
Phenathrene	0.07	0		50	0.28	67	0.16
Anthracene	0.01	35	0.01	10	0.05	50	0.03
Fluoranthene	0.02	100	0.18	80	0.24	100	0.24
Pyrene	0.05	82	0.23	60	0.19	83	0.20
Benzo (a) anthracene	0.02	71	0.17	60	0.11	67	0.10
Chrysene	0.02	82	0.24	60	0.20	83	0.12
Benzo (k) fluoranthene	0.02	65	0.09	50	0.08	67	0.15
Benzo (b) fluorene	0.05	53	0.08	50	0.08	67	0.15
Benzo (a) pyrene	0.04	65	0.10	50	0.07	50	0.10
Indeno (1,2,3-cd) pyrene	0.04	29	0.05	10	0.05	50	0.08
Total PAHs			1.30		1.54		1.58

Radiodating was used by Sherman et al. (1990) to date a sample taken from the centre of Moberly Bay (Station 704, Figure 3.15). No evidence of disturbance of the surficial layers was noted. The dates established from the Pb-210 profiles agreed very closely with appearance of Cs-137 within the core. Established dates were also corroborated with other fluctuations in chemical profiles and core appearance that correspond to dates of historical changes at the mill or other events significant to the core record. Dates established for the period after 1940 were considered accurate to within 2 to 3 years. Due to the relatively high sedimentation rate in the core sample area caused by the suspended solids loading from Blackbird Creek, the resolution of section age over the period of mill operation (1949 to present) is considered to be even finer; within 2 years. It is expected that the sedimentation rate decreased as a result of the 1989 installation of an aerated lagoon system by the mill which reduced the amount of organic matter discharged in the effluent (Chapter 4).

The core profile of tetrachlorodibenzofuran (4CDF) concentration (Figure 3.32) showed relatively high values which abruptly dropped to undetectable levels (<60 pg/g) below a depth of 10 cm. This drop corresponds to 1973 and the abruptness of the concentration change from 1973 to 1975 is not consistent with a decay or gradual introduction of 4CDF into the sediment. Rather, the profile suggests that a sudden process change at the mill had resulted in production of 4CDF following 1973 and continuing to the time of sampling (1988).

The abrupt appearance of 4CDF in the sample following 1973 may correspond to the mill changing from 'cold' to 'hot' chlorine bleaching. Warmer temperatures used in the second process favour the formation of 4CDF. Another possibility is that the use of oil-based brownstock defoamers, which have recently been shown to contain dioxin and furan precursors, may be the cause.

Concentrations of octachlorodibenzo-p-dioxins (8CDD) in the same core (Figure 3.32) showed moderate values similar to those of remote areas of Lake Superior (Czuczwa and Hites 1986). No abrupt change in concentration with depth in the core was found and measurable concentrations of 8CDD were noted in core segments that predated the start of mill operations.

Figures 3.33 and 3.34 illustrate concentrations of mercury, lead, zinc, cadmium, manganese, copper, loss on ignition (fibre) and total organic content in a core sample from Station 704 in Moberly Bay collected in 1988 (Sherman 1991). Concentrations of zinc, cadmium, copper, loss on ignition and total organic carbon increase in the more recent years. Lead and manganese show little or no change over time. The high levels of zinc in sediments is interesting as this metal is not added to any processes in the mill. However, as noted earlier, metals are naturally taken up by trees and stored in wood fibre. It may be that during the pulping process, metals are released from the pulp and concentrated in the wastewater. Similarly, increased zinc concentrations in recent sediments may be a result of decreased water usage on a pulp production basis in recent years.

The results of the 1987 and 1988 surficial sampling described earlier suggested that copper and manganese and possibly cadmium concentrations reflected geochemical characteristics of the sediments in the region rather than pollution from a single source (Section 3.2.4). The increasing concentrations of cadmium and copper in more recent years (Figures 3.33 and 3.34, however, suggests that anthropogenic sources are more likely than gross regional geochemical characteristics. The atmospheric deposition of trace metals is known to contribute relatively large loadings to Great Lakes, particularly those remote from industrial and urban activity (Nriagu 1986, 1990). The results of the sediment core data which show increasing concentrations of cadmium and copper (as well as zinc) throughout the industrial era (i.e., since the late 1800s) combined with the surficial results showing ubiquitous concentrations provides strong evidence for a significant atmospheric component to the occurrence of these metals.

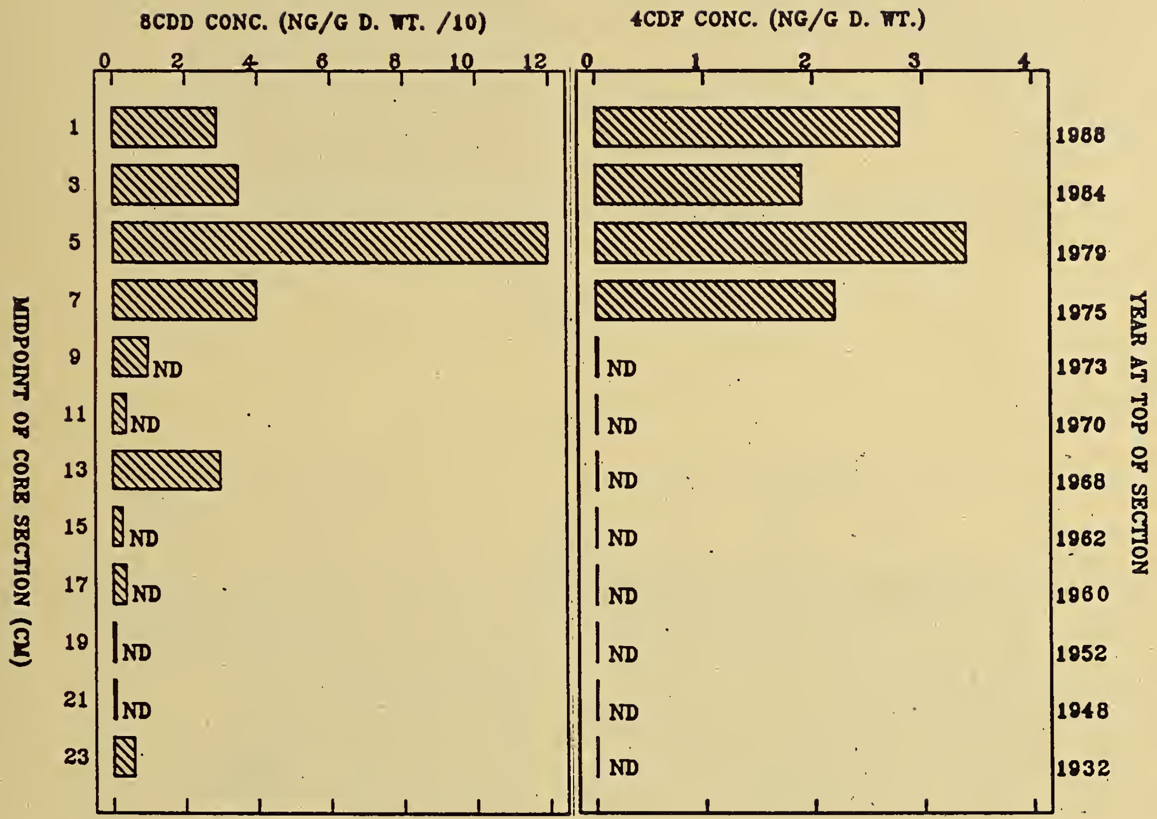
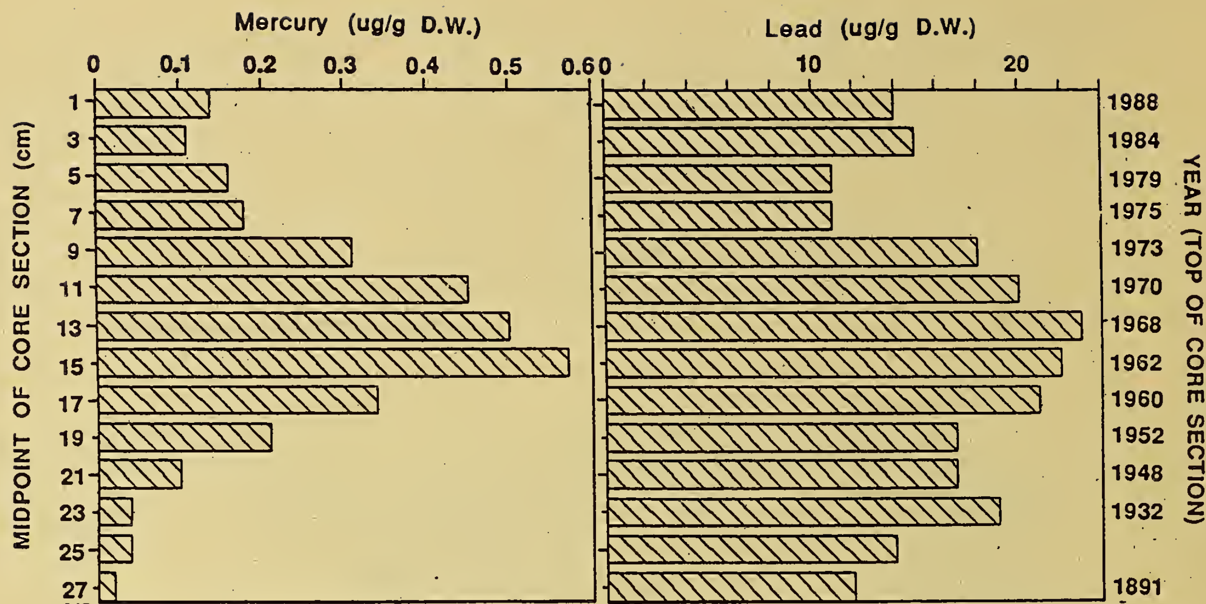
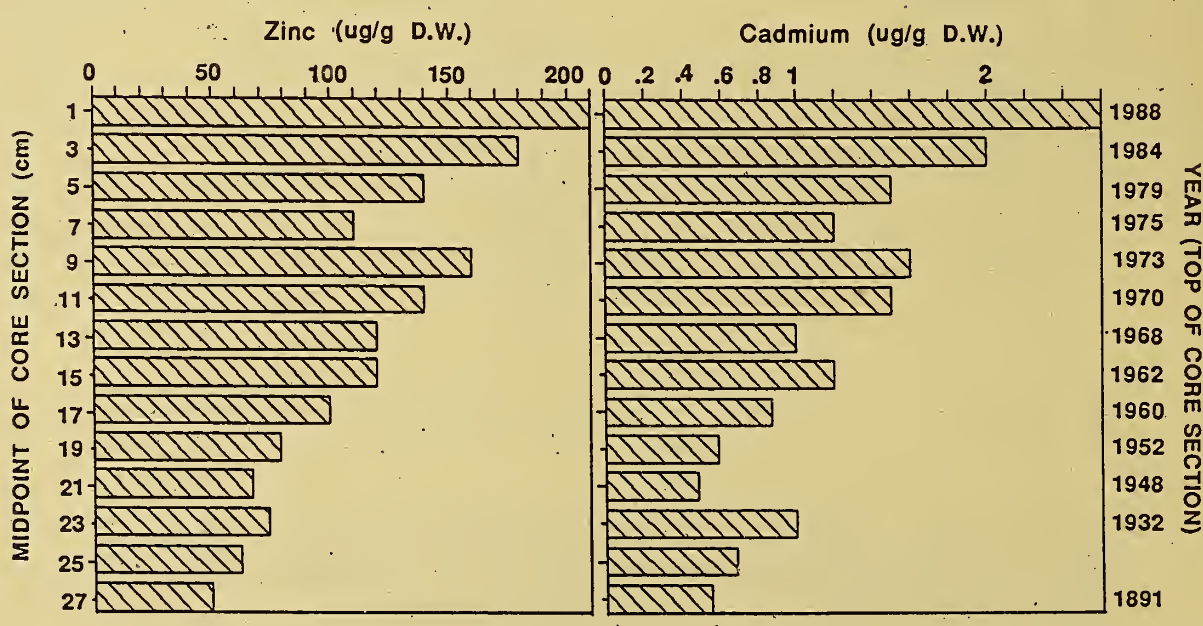


Figure 3.32

Concentration pattern of tetrachlorodibenzofurans (4CDF) and octachlorodibenzo-p-dioxins (8CDD) in a sediment core collected in 1988 at Station 704 in Moberly Bay (Sherman et al 1990). Station location shown in Figure 3.15.



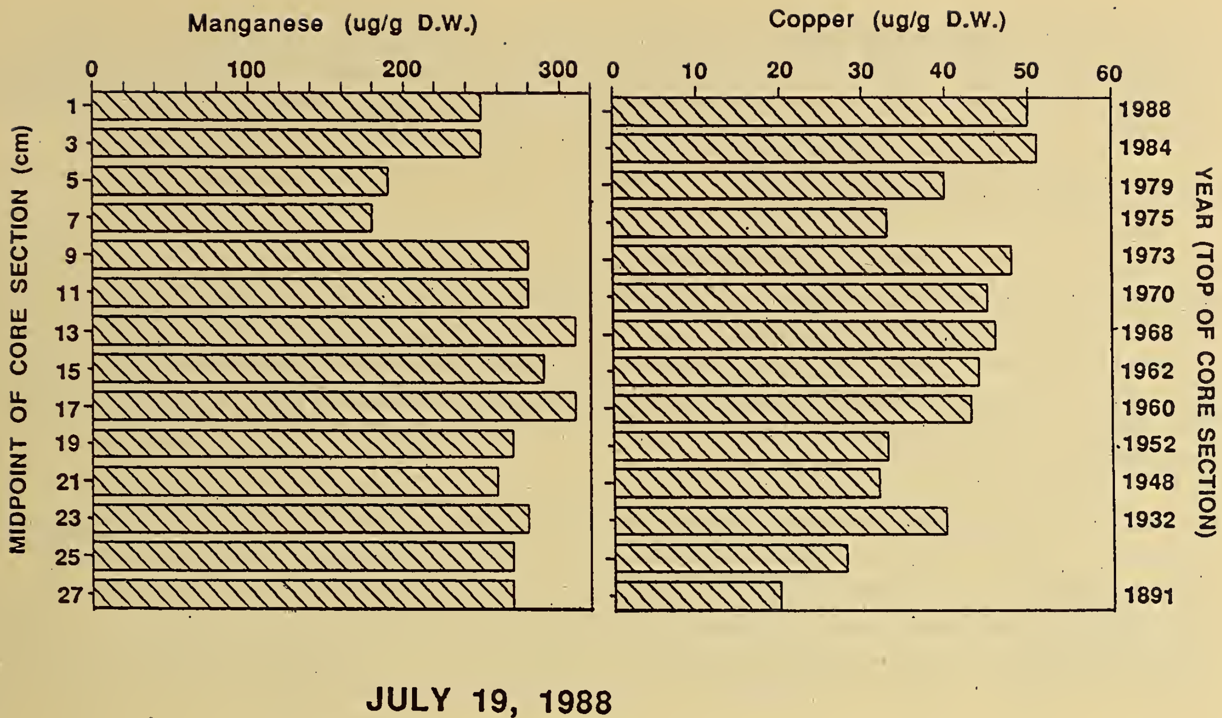
JULY 19, 1988



JULY 19, 1988

Figure 3.33

Concentrations of mercury, lead, zinc and cadmium in a sediment core collected in 1988 at Station 704 in Moberly Bay (Sherman 1991). Station location is shown in Figure 3.15.



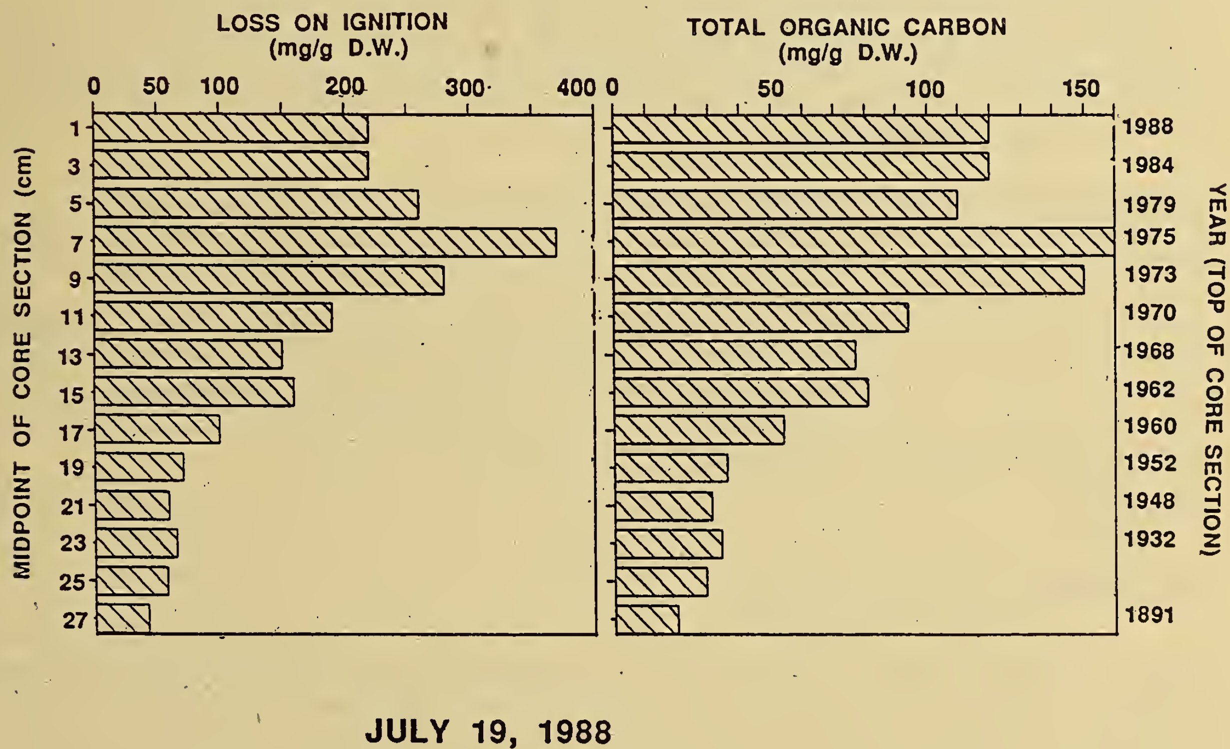


Figure 3.34

Concentrations of manganese, copper, fibre (loss on ignition) and total organic carbon in a sediment core collected in 1988 at Station 704 in Moberly Bay (Sherman 1991). Station location is shown in Figure 3.15.

Between 1972 and 1978, the Kimberly-Clark mill used a mercury anode chlorine generation unit, which resulted in mercury losses from the gradual degeneration of the anode. Additional mercury and lead (from the lining of the reaction chamber) were likely discharged during this period. Increased mercury and lead levels in the core section corresponding to this time period reflects their use by the mill (Figure 3.33).

3.2.7 Sediment Quality Summary

The results of geophysical investigations of sediments from the Jackfish Bay AOC during 1987 and 1988 identified the presence of three depositional basins in which fine-grained (mud) sediments dominated. These basins correspond to Moberly, Jackfish and Tunnel Bays. The sediments of Moberly Bay have the highest percentage of organic material and consequently the most reducing conditions. The presence of the organic material is attributed primarily to the mill effluent which enters via Blackbird Creek. The sediments of the three basins are variously contaminated due to a variation in sources and to processes which affect their accumulation and availability.

Contaminants which exceed either the Dredged Material Disposal Guidelines and/or the Lowest Effect Level of the draft Provincial Sediment Quality Guidelines, based on surveys undertaken during 1987 and 1988 include: oil and grease, total organic carbon, total phosphorus, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, hexachlorobenzene and total PCBs. TKN measured in 1981 also exceeded guidelines. In addition, high concentrations of certain phenolic compounds, resin and fatty acids, and dioxins and furans, for which no guidelines are available, contaminate sediments within the AOC.

Contaminants which are attributed to the Kimberly-Clark effluent based on their temporal or spatial distribution patterns, either currently or historically, include total organic carbon, TKN, mercury, zinc, total PCBs, hexachlorobenzene, phenolic compounds, resin and fatty acids and tetrachlorodibenzofurans. The most likely sources for the higher chlorinated dibenzo-p-dioxins and furans, PAHs, and certain metals (cadmium and copper) are diffuse and point sources remote from the AOC and contributed via atmospheric deposition. Cadmium and copper concentrations may also reflect local geochemical conditions along with chromium, iron, nickel and manganese. The distribution patterns of total phosphorus, arsenic and lead do not clearly identify likely sources.

The presence of PCBs in sediment within Moberly Bay may be due to their former use in electrical equipment at Kimberly-Clark. Detectable concentrations of organochlorine pesticides were found only in Moberly Bay sediments.

Although the data are not sufficient to identify statistically significant trends over time, a comparison of data collected in 1981 with data collected in 1987/88 and the historical record identified in sediment cores from Moberly Bay suggest certain trends. Generally, concentrations of oil and grease, total phosphorus, and manganese appear to be fairly constant over time. Total organic carbon, cadmium, copper and zinc appear to be increasing in concentration whereas mercury and total PCBs are decreasing.

3.3 BIOTA

3.3.1 Benthic Macroinvertebrates

Benthic macroinvertebrates are useful organisms for determining environmental quality. They are relatively immobile and ubiquitous, hence, they integrate the effects of water and sediment quality conditions at any one location and allow for comparisons among areas which are affected differently by pollution. In addition, because different species have different sensitivities to contaminants, environmental quality in any given area can be determined by describing benthic communities with regard to: the presence or absence of certain species; the overall abundance of taxa and species; density and distribution of taxa; diversity and richness of

the community; and correlating the benthos with sediment conditions. In addition, the evaluation of temporal changes in any or all of these components can be used to determine whether environmental quality is worsening or improving.

Beak Consultants Ltd prepared a report in 1988 (Beak Consultants 1988) summarizing the results of biological surveys conducted in Moberly, Tunnel and Jackfish Bays in 1969, 1975 and 1987. The authors summarized benthic species richness and distribution as well as community structure for each of the survey years and identified important temporal trends from 1969 to 1975 and 1975 to 1987.

3.3.1.1 Species Density and Diversity

The Beak report concluded that the greatest species diversity was detected in association with aquatic vegetation. This observation can be explained by the fact that aquatic vegetation provides benthos with diverse habitat, suitable for an array of benthic species. In contrast, limited species diversity was observed in odorous sediments where much organic matter had accumulated. The authors suggested that organic loadings from Kimberly-Clark Canada Inc. may have degraded benthic habitat and associated benthos.

Total organism density was depressed in the extreme west due to the effects of mill effluent entering from Blackbird Creek, followed by a density rise to the immediate east due to the effects of organic enrichment, followed by a gradual decline to the east. The enrichment of west-central areas of Moberly Bay and Jackfish Bay was concluded to be consistent with the observed pattern of dispersion of the effluent plume from Blackbird Creek (Beak Consultants 1988).

Pontoporeia hoyi density decreased dramatically between 1969 and 1987, indicating that environmental quality was deteriorating over this period. These organisms are extremely sensitive to pulp mill effluent. In 1969, this organism was essentially absent in central and western Moberly Bay and a few locations in the western portion of inner Jackfish Bay. Densities were high in Tunnel Bay, although they were lower in the eastern portions of inner and outer Jackfish Bay. However, by 1987, there were no *P. hoyi* in any of Moberly Bay or the western portion of Jackfish Bay (Figure 3.35). Densities were found to have continued to decrease in Tunnel Bay, and there were substantial decreases in eastern and central portions of Jackfish Bay.

Conversely, tubificids, which are pollution tolerant, increased in density and extent of high density between 1969 and 1987, especially in Moberly Bay and the western and central section of Jackfish Bay (Figure 3.36). The maximum density in 1969 was 30,000/m^3, whereas in 1987, the maximum density was 196,000/m^3. The authors noted that these results indicate that Jackfish Bay is gradually becoming enriched, possibly as a result of the cumulative effects of organic loadings from the mill (Beak Consultants 1988).

3.3.1.2 Benthic Community Impairment

Cluster analysis using the quantitative benthic data identified four distinct benthic communities or clusters as existing during each of the three survey years. Discriminant analysis of these clusters, utilizing environmental characteristics associated with the benthic sampling locations, identified sediment particle size, water depth, organic matter accumulation in the sediments, and the presence of aquatic vegetation as the most important factors distinguishing among the four benthic clusters. In general, the clusters which were found to be most characteristic of degraded environmental conditions were most often distinguished by a fine-textured sediment (Beak Consultants 1988).

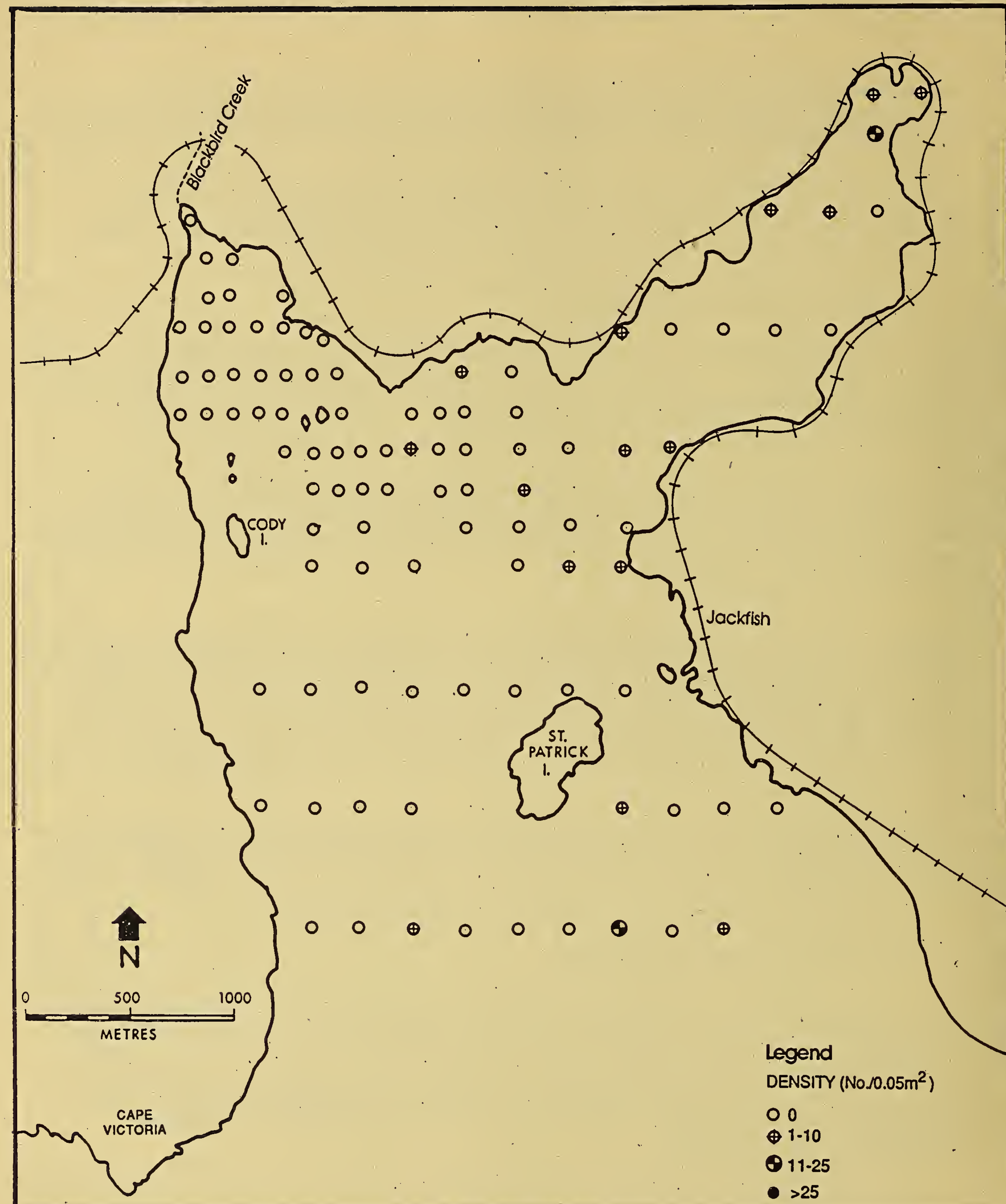


Figure 3.35

Distribution of Pontoporeia hoyi in the Jackfish Bay AOC in 1987 (Beak Consultants 1988).

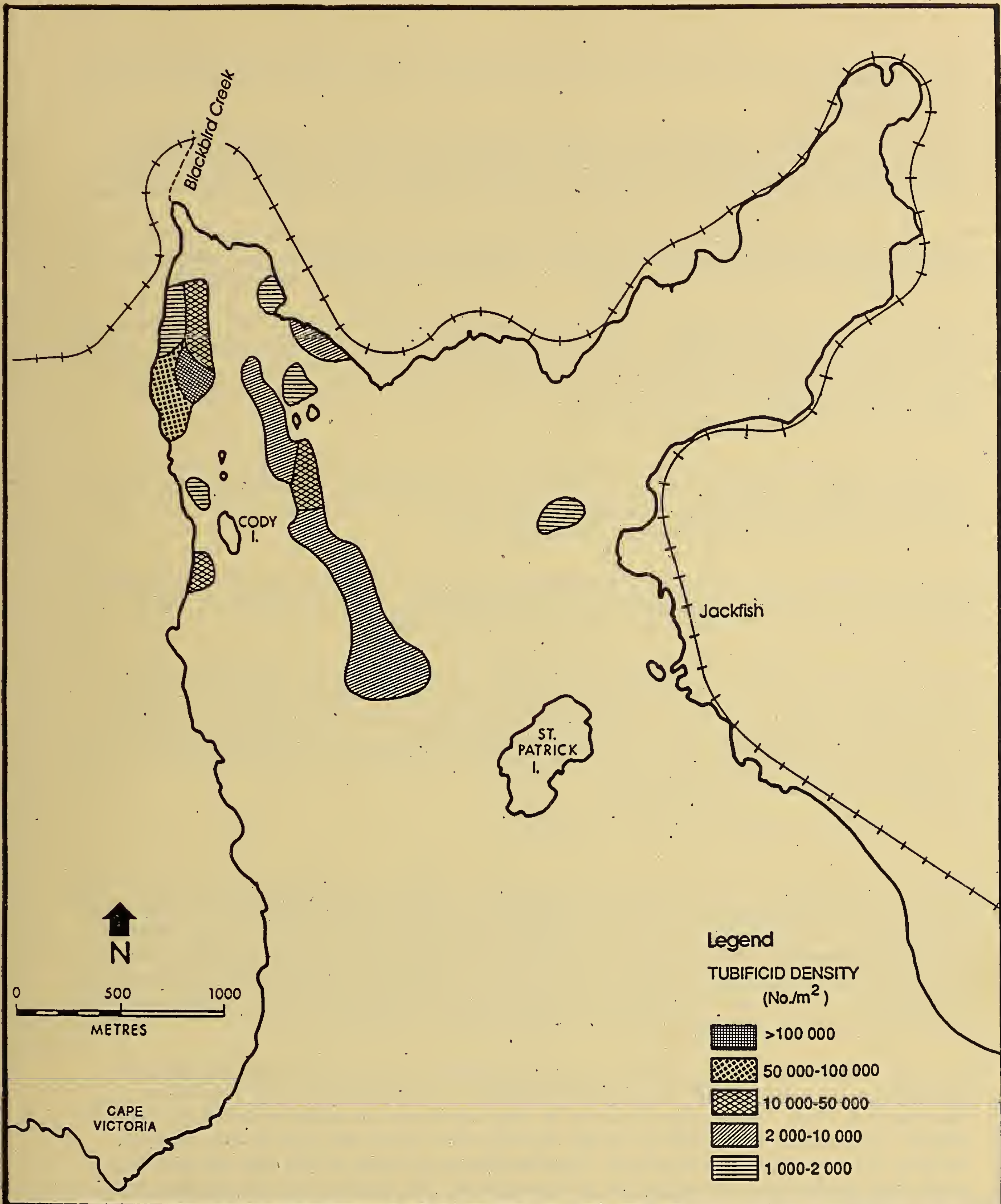


Figure 3.36

Density zones of tubificids in the Jackfish Bay AOC during 1987 (Beak Consultants 1988).

Figures 3.37 and 3.38 illustrate the distribution of the four benthic community clusters identified for 1969 and 1987, respectively.

In 1969, 1975 and 1987, one benthic cluster (cluster 1) consisted of two benthic subgroups; a deepwater, oligotrophic subgroup (nonimpaired community) and a small subgroup near the mouth of Blackbird Creek (severely impaired community). Both subgroups revealed low benthic densities and relatively low diversities.

The pollution tolerant species *Tubifex tubifex* was found to characterize severely impaired communities in the vicinity of the mill influence (Figures 3.37 and 3.38). This zone, which remained relatively constant at 0.2 to 0.3 km, was thought to be a result of the toxicity or loss of habitat resulting from fibre deposition.

Beyond the zone of severe impairment (cluster 1), an additional cluster (cluster 2), characterized by medium diversity and dominated by oligochaetes, occurred during 1969 and 1975 and was interpreted as representing slightly degraded conditions influenced by mill inputs (Beak Consultants 1988). Clusters 3 and 4 identified during these two surveys were interpreted as representing 'relatively unimpaired' to unimpaired conditions with no obvious effects from pulp mill discharges.

The 1987 survey, however, revealed two clusters (clusters 2 and 3) in addition to the severely degraded community (cluster 1) indicative of organic enrichment and representing impaired conditions (Figure 3.38). The authors interpreted this finding as representing increased and more widespread organic enrichment of Moberly Bay and western Jackfish Bay (Beak Consultants 1988).

Sediment chemistry results, determined from sediments sampled coincidently with the 1975 benthic sampling, identified the two impaired benthic communities as having the highest mean concentrations of copper, cadmium, lead, zinc, loss on ignition and TKN (Beak Consultants 1988).

As well as a greater number of impaired communities, the overall size of the zone of impairment also increased between 1969 and 1987. In 1969 the degraded zones (clusters 1 and 2, Figure 3.37) extended to Cody Island in Moberly Bay, however, by 1987 it extended west of St. Patrick Island and into Tunnel Bay (clusters 1 and 2, Figure 3.38). This increase was not thought to correspond to substantial increases in suspended solids levels or BOD_5 loadings but, as in the case of species diversity changes, likely represent the cumulative effects of mill discharges with time.

3.3.1.3 Benthic Contaminant Body Burdens

Because of their ubiquitous distribution and lack of mobility, benthic macroinvertebrates also serve as useful biomonitors of chemical conditions within areas of interest. Analysis of contaminants within benthos may be undertaken for resident populations in order to determine chemical burdens within the local population, or by introducing noncontaminated organisms for specified periods of time to determine the rate and nature of bioaccumulating chemicals. These methods have been used extensively to characterize and monitor chemical contamination in several AOCs, particularly those within the connecting channels. However, there have been very few studies of chemical body burdens in benthic fauna of the Jackfish Bay AOC.

Opposum shrimp (*Mysis relicta*) collected off the mouth of Moberly Bay coincident with the collection of sediment samples during the 1987/88 survey (Section 3.2.5.3) were also tested for dioxins and furans (Sherman et al. 1990). The congener pattern for *M. relicta* was found to be similar to that of the mill effluent. 2,3,7,8-tetrachlorodibenzofuran was the dominant isomer found with traces of other congeners including 2,3,7,8-tetrachlorodibenzo-p-dioxin. Octachlorodibenzo-p-dioxins (8CDD) were not detected in mysids from Jackfish Bay or the control site off Lawson Island. This indicated that, although there were moderate 8CDD levels in sediments, they were not taken up by the shrimp.

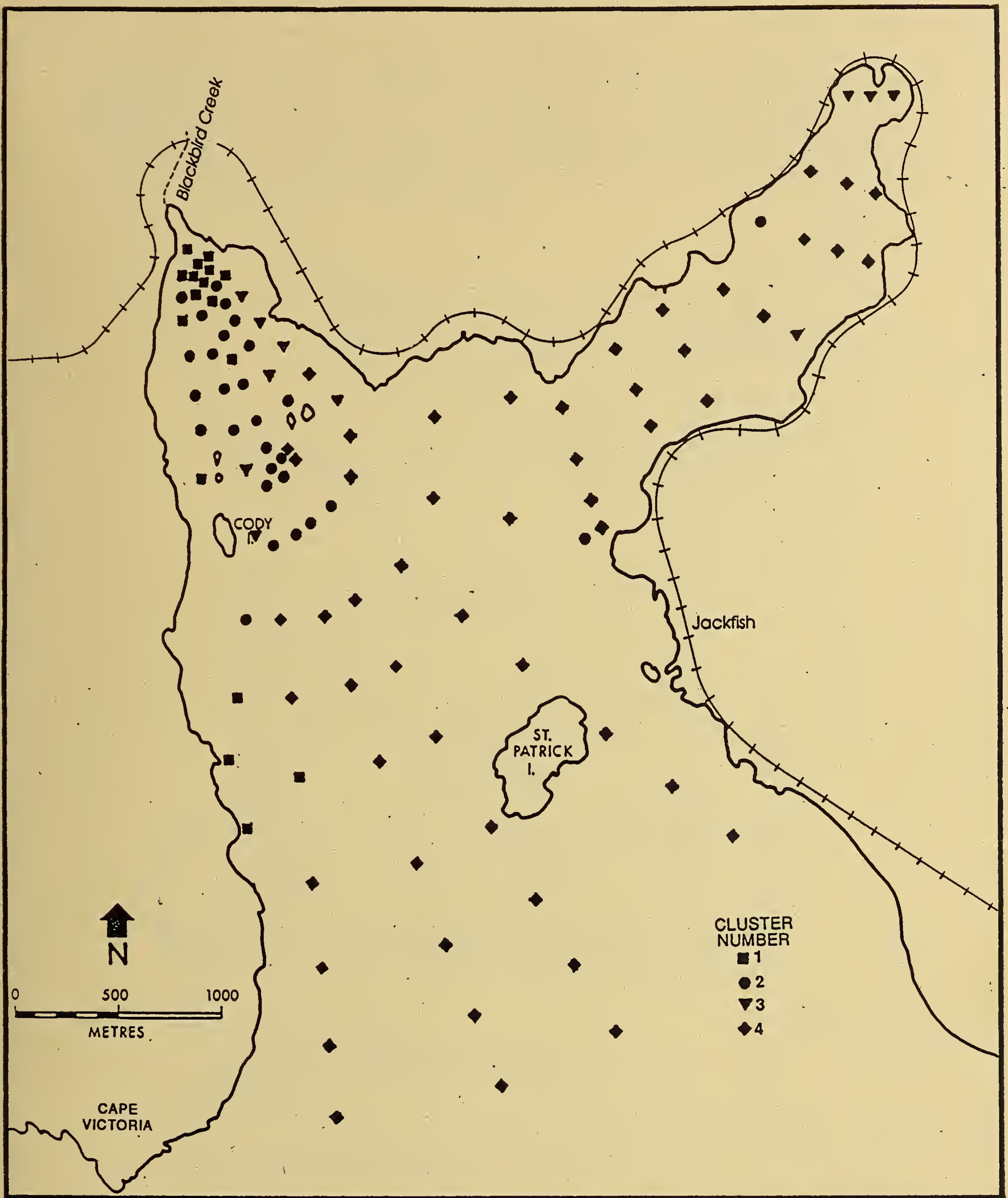


Figure 3.37

Benthic community clusters during 1969 (Beak Consultants 1988).

Figure 3.38

Benthic community clusters during 1987 (Beak Consultants 1988).

Introduced caged mussels (*Elliptio complanata*) and white sucker (*Catostomus commersoni*) collected in Moberly Bay by other researchers displayed similar congener patterns to mysids. Table 3.15 summarizes the information. The higher chlorinated dioxins and furans, including the 6CDD/6CDF, 7CDD/7CDF and 8CDD/8CDF congeners, were mostly not detectable in the biota. However, the 4CDD/4CDF congeners were common to mysids, mussels and white suckers. According to the data in Table 3.15, the most toxic of these (2,3,7,8-TCDD) constituted the entire fraction of the tetrachlorinateddibenzo-p-dioxins in mysids. It is not known if this is also true for the mussels or suckers.

Table 3.15 Concentrations of dioxins and furans (pg/g wet wt.) found in opposum shrimp (*Mysis relicta*) at the mouth of Moberly Bay and introduced caged mussels and white sucker (in Moberly Bay) from the Jackfish Bay AOC (Sherman et al. 1990).

Congener	Mysis*	Mussels†	White Suckers‡
2378 - T4CDD	9		
4CDD	9	<2	7
5CDD	<7	ND†	ND†
6CDD	<20	ND‡	ND‡
7CDD	ND(9)	ND‡	ND(4)
8CDD	INT	ND(7)	ND(7)
4CDF	48	34	44
5CDF	16	ND‡	<3
6CDF	<4	ND‡	ND‡
7CDF	<4	ND(4)	ND(6)
8CDF	ND†	ND(7)	ND(8)
N	2	4	4
%lipid	1.20	2.23	4

* data of Sherman (1990)
† data of A. Hayton (OMOE, unpublished)
‡ data of I. Smith (OMOE) and M. McMaster (U. Waterloo) (unpublished)

INT = level of 5CDD in spiked procedure blank was approximately equal to the levels found in the samples

3.3.2 Fish

3.3.2.1 Fish Communities

The Jackfish Bay fish community includes at least 31 species (Table 3.16), and is dominated by species from the cold water assemblage. This community varies considerably, from the heavily contaminated northern portion of Moberly Bay, which produced the lowest Integrated Biotic Index (IBI) for northern Lake Superior during a 1986 electrofishing survey, to the relatively productive northern portion of Tunnel Bay (B.A.R. Environmental 1987). The southern portion of Jackfish Bay is strongly influenced by Lake Superior and is characterized as oligotrophic system, low in fish productivity and abundance. The following species are most common to the AOC: lake trout, rainbow trout, lake whitefish, round whitefish, lake herring, lake chub, chinook salmon, coho salmon, pink salmon, rainbow smelt, common white suckers and longnose suckers. The introduction of exotic fish species such as rainbow trout, chinook salmon and pink salmon has increased species diversity, however, native species continue to dominate the community structure.

Lake trout has persisted as the dominant piscivore in Jackfish Bay, although Pacific salmon populations appear to be increasing along the north shore of Lake Superior. Natural reproduction of chinook and coho salmon occurred in numerous northern rivers during the 1980s and reported catches from sport and commercial fisheries also increased.

A major shift in the forage base occurred with the immigration of rainbow smelt into Lake Superior in the 1930s. Smelt replaced lake herring as the primary food source for lake trout, with little apparent effect on lake trout, as both smelt and herring appeared to be suitable forage (Anderson and Smith 1971). The abundance of forage fish in Jackfish Bay has not been investigated.

The sea lamprey have depressed Lake Superior fish stocks since the 1950s (Anonymous 1986). Chemical control was introduced in the mid-1960s, and lamprey populations have remained in check since this period. Wounding rates estimated for commercially caught lake trout are presently considered moderate. Wounding rates in Management Zone 18 spanning a five year period (1982 to 1986) ranged from 1.2 to 11.5 percent. The Steel River is the only Lake Superior tributary in Zone 18 which is currently treated with TFM lampricide on a three to five year cycle.

3.3.2.2 Toxicity and Mutagenicity

In July 1983, surface waters in Jackfish Bay were found to be acutely lethal to rainbow trout, up to a distance of 1.5 km from the mouth of Blackbird Creek (Flood et al. 1986). In October 1989, the Kimberly-Clark mill brought a secondary effluent treatment facility on line. In addition to reducing organic loadings in the final effluent, this treatment facility was expected to reduce effluent toxicity. In July 1990, toxicity testing was conducted in Jackfish Bay to determine the effectiveness of this new facility (Flood 1990).

Results from this study indicated that the resultant final effluent is non-lethal in 96-hour laboratory bioassays with rainbow trout. Similarly, the effluent, once diluted with the receiving waters in Moberly Bay, is not toxic to fathead minnow or rainbow trout in caging studies. The LC50 using *Daphnia magna* in the laboratory was found to be greater than 100 percent. That is, a non-diluted effluent sample could not kill 50 percent of the test organisms. Thus, the final effluent was found to meet its current control order with regards to toxicity, and the toxicity criteria proposed under Ontario's Municipal-Industrial Strategy for Abatement (MISA).

Table 3.16 Fish species occurring within the Jackfish Bay AOC.

Species	Common name	Electro-shocking*	Commercial Catch†	Netting Surveys‡
Petromyzon marinus	sea lamprey		●	
Acipenser fulvescens	lake sturgeon		●	
Alosa pseudoharengus	alewife	●		
Oncorhynchus gorbuscha	pink salmon		●	
O. kisutch	coho salmon		●	
O. tshawytscha	chinook salmon		●	●
O. mykiss	rainbow trout	●	●	●
Salmo trutta	brown trout		●	
S. fontinalis	brook trout		●	
S. namaycush	lake trout		●	
Coregonus artedii	lake herring		●	●
Coregonus spp.	chub spp.		●	●
C. clupeaformis	lake whitefish	●	●	●
Prosopium cylindraceum	round whitefish		●	●
Osmerus mordax	rainbow smelt	●	●	
Esox lucius	northern pike		●	
Chrosomus eos	northern redbelly dace			●
Cyprinus carpio	carp	●		
Notropis atherinoides	emerald shiner			●
N. hudsonius	spottail shiner	●		●
Catostomus catostomus	longnose sucker	●	●	●
C. commersoni	common white sucker	●	●	●
Lota lota	burbot	●	●	●
Pungitius pungitius	ninespine stickleback	●		
Percopsis omiscomaycus	trout perch	●		
Perca flavescens	yellow perch	●		●
Stizostedion vitreum	walleye		●	●
Etheostoma nigrum	johnny darter			●
Percina caprodes	logperch			●
Cottus bairdi	mottled sculpin	●		
C. cognatus	slimy sculpin	●		
Couesius plumbeus	lake chub	●		

Species list compiled from the following:

* B.A.R. Environmental (1986).

† Lake Superior Fisheries Unit, commercial catch records.

‡ OMNR and OMOE netting surveys.

Considerable research has gone into the study of sublethal effects of the mill effluent on fish in Jackfish Bay (McMaster et al. 1991a&b, Munkittrick 1990, Munkittrick et al. 1991a,b&c, Smith et al. 1990, 1991). Results from studies on local white sucker collected in 1988 (Munkittrick et al. 1991c) indicated that these fish grew more slowly than reference fish, had smaller gonads, lower fecundity with age, an absence of secondary sex characteristics in males, failure of females to show an increase in egg size with age, reduced serum estradiol and testosterone (steroids) concentrations, and greater hepatic mixed-function oxidase (MFO) activity. Tests with lake whitefish and longnose sucker produced the same results as for white sucker. These three fish species are benthic species which makes them useful for monitoring the effects of contaminants in sediments, on aquatic life.

MFOs are enzymes located in the liver that oxygenate natural and synthetic chemicals, preparing them for excretion or other destinations (Smith et al. 1991). Many chemical contaminants such as PCBs, dioxins, furans and PAHs, are potent inducers of the activity of these enzymes (Smith et al. 1991). Smith et al. (1991) also noted that induced MFO activities have been associated with reductions in reproduction and the susceptibility of various species to develop cancers.

PCBs were not implicated by Smith et al. (1990, 1991) as the cause for the induction of MFO activity in white suckers from Jackfish Bay because there was no correlation with PCB concentration and observed MFO activities. They noted that dibenzo-p-dioxins and furans are potent inducers and concluded that the MFO induction in suckers from Jackfish Bay is most likely due to the presence of dioxins, furans and resin acids in the discharge from Kimberly-Clark. Smith et al. (1991) also correlated the induction of MFOs in Jackfish Bay with disruptions of the reproductive process observed by Munkittrick et al. (1990).

After secondary treatment of the mill effluent was brought on line in October 1989, liver weights in whitefish and white sucker decreased (though they were still larger than reference fish) but MFO activity was not decreased (Munkittrick et al. 1991b). However, after a two week mill shutdown, there was no MFO induction in longnose sucker, MFO activity was reduced in white sucker, and the impact zone for MFO induction in lake whitefish was reduced. From these observations, the authors noted that: i) secondary treatment was not successful in removing MFO activating compounds; ii) induction was not related to sediment contamination with persistent compounds; and iii) MFO inducing agent(s) are rapidly cleared by fish. It was also found that neither secondary treatment or a temporary shutdown returned testosterone and estradiol levels to normal levels in white and longnose sucker (Munkittrick et al. 1991b).

The induction of MFO activity in white suckers collected from Jackfish Bay in the summer of 1988, prior to secondary treatment, was correlated by Smith et al. (1991) with an "abnormal incidence of liver neoplasms (cancers)". Greater than 20 percent of lake whitefish caught in Jackfish Bay during August 1989 and August/September 1990 had unexplainable external lesions which did not appear to be related to predatory attack or infection (Munkittrick et al. 1991a). The presence of these lesions in an isolated unpopulated bay which has received large volumes of pulp mill effluent, as well as the absence of reports of similar wounding in other lake whitefish, lead the authors to suggest an association between the lesions and the discharge of bleached kraft mill effluent.

3.3.2.3 Sport Fish Contaminant Body Burdens

One of the problems noted by the IJC in designating Jackfish Bay as an Area of Concern was the presence of contaminants (mercury and PCBs) in sport fish in concentrations which restricted their consumption by humans. The 1989 "Guide to Eating Ontario Sport Fish" listed Jackfish Bay as unrestricted consumption of whitefish and cisco as well as lake trout up to 45 cm in length (OMOE/OMNR 1989). Lake trout longer than 45 cm were limited to long-term consumption of no more than 0.2 kg/week due to mercury concentrations between 0.5 and 1.0 μg/g and/or PCBs greater than 2.0 μg/g. Children under 15 and women of childbearing age were not advised to eat any of these fish. However, the 1990 and 1991 guides identified

consumption of lake trout up to 65 cm in length as unrestricted with respect to mercury and PCB concentrations (OMOE/OMNR 1990, 1991). In addition, the 1991 Guide to Eating Ontario Sport Fish noted that consumption of whitefish, cisco and white sucker to 45 cm in length was also unrestricted. However, the guide notes that the consumption of lake trout greater than 55 cm may need to be restricted for consumption due to concentrations of dioxins and furans expressed as toxic equivalents of 2,3,7,8-tetrachlorodibenzo-p-dioxin.

As of 1991, fish consumption restrictions were in place for Jackfish Lake due to mercury (yellow perch) and mercury and/or PCBs (northern pike and walleye). However, this lake is considered to be outside the influence of the mill effluent and, hence, mercury concentrations >1.5 $\mu g/g$ in yellow perch between 35 and 45 cm in length is likely due to natural background sources.

Table 3.17 lists the number of detections and the range of concentrations of 14 contaminants measured in lake trout collected for the OMOE/OMNR Sportfish Consumption Program as well as levels of 2,3,7,8-TCDD and 2,3,7,8-TCDF in white suckers collected during 1988. Concentrations of all contaminants tended to be low and there were no exceedences of Ontario's fish consumption guidelines for the protection of human consumers. The GLWQA Specific Objectives for the protection of piscivorous wildlife were exceeded by maximum concentrations of total PCBs (0.1 $\mu g/g$) in lake trout but not for mirex (any detectable concentration).

3.3.2.3 Juvenile Fish Contaminant Body Burdens

Spottail shiners (*Notropis hudsonius*) are restricted to localized nearshore habitats and, as such, have been found to be useful biomonitors (spatially and temporally) of contaminant inputs (Suns et al. 1991). As important forage fish, these and other cyprinids provide an important link in the transfer of contaminants to higher trophic levels. Juvenile (young-of-the-year) spottail shiners have been used for contaminant monitoring in all the Great Lakes and connecting channels as part of the Great Lakes International Surveillance Plan since the mid 1970s.

Young-of-the-year spottail shiners have been collected at Jackfish Bay since 1979. Analyses have been undertaken for total PCBs, DDT, mirex, chlordane, BHC, hexachlorobenzene (HCB) and octachlorostyrene (OCS). The results of these analyses are presented in Table 3.18. Although low concentrations of BHC and HCB were detected during 1983 and 1986, respectively, these chemicals along with mirex, chlordane and OCS are essentially not detectable in young-of-the-year spottail shiners from Jackfish Bay (Table 3.18). Trace or detectable concentrations of PCBs and DDT were measured during most years, however, PCBs were not detected and DDT was detected at only trace amounts during the most recent collections (1988). No significant correlations ($p>0.05$) with time were found for total PCB, DDT and chlordane residues in spottail shiners from Jackfish Bay (Suns et al. 1991).

The GLWQA Specific Objectives for the protection of piscivorous wildlife due to PCBs, DDT and mirex were not exceeded during any of the five years of sampling (Table 3.18).

3.3.3 Biota Summary

The biota within the Jackfish Bay AOC, including benthic macroinvertebrates and sport fish, have been impacted as a result of the mill effluent discharged through Blackbird Creek. Densities of benthic macroinvertebrates tend to be lowest along the western portion of Moberly and Jackfish Bays due to the influence of the effluent plume from Blackbird Creek. Between 1969 and 1987, maximum densities of pollution tolerant organisms (tubificids) increased by more than six times while densities of pollution intolerant organisms (*Pontoporeia hoyi*) decreased dramatically. During this period the extent of tubificids also increased in concert with a decrease in the extent of *P. hoyi*. Whereas in 1969 only the central portion

Table 3.17 Frequency of detection and concentrations ($\mu g/g$) of mercury, PCBs, dioxins, furans, and organochlorine pesticides in lake trout collected in 1989 and of 2,3,7,8-TCDD and 2,3,7,8-TCDF in white suckers collected in 1988 from Jackfish Bay.

Parameter	Ontario Fish Consumption Guidelines	Detection Limit	No. Detected/ No. Samples	Range
Lake Trout (1989)[1]				
Mercury	0.5	0.01	20/20	0.6-0.38
Total PCBs	2.0	0.02	20/20	0.04-0.44
Mirex	0.1	0.005	0/20	ND
Hexachlorobenzene	-	0.001	16/20	ND-0.004
pp-DDE	-	0.001	19/20	ND-0.117
α-BHC	-	0.001	18/20	ND-0.009
γ-BHC	-	0.001	8/20	ND-0.001
α-chlordane	-	0.002	20/20	0.002-0.017
γ-chlordane	-	0.002	19/20	ND-0.007
pp-DDD	-	0.002	5/20	ND-0.001
Toxaphene	3.0	0.2	18/20	ND-1.47
2,3,7,8-TCDD	-	0.000002	5/5	0.0000029-0.0000113
1,2,3,7,8-5PCDD	-	"	5/5	0.0000036-0.0000055
1,2,3,4,7,8-6HCDD	-	"	0/5	ND
1,2,3,6,7,8-6HCDD	-	"	0/5	ND
1,2,3,7,8,9-6HCDD	-	0.000002	0/5	ND

Table 3.17 (cont'd)

Parameter	Ontario Fish Consumption Guidelines	Detection Limit	No. Detected/ No. Samples	Range
1,2,3,4,6,7,8-7HCDD	-	"	1/5	ND-0.0000011
8OCDD	-	"	5/5	0.0000016-0.0000035
2,3,7,8-TCDF	-	"	5/5	0.000020-0.000058
1,2,3,7,8-5PCDF	-	"	5/5	0.0000023-0.0000080
2,3,4,7,8-5PCDF	-	"	5/5	0.0000015-0.0000036
1,2,3,4,7,8-6HCDF	-	"	0/5	ND
1,2,3,6,7,8-6HCDF	-	"	0/5	ND
1,2,3,7,8,9-6HCDF	-	"	0/5	ND
2,3,4,6,7,8-6HCDF	-	"	0/5	ND
1,2,3,4,6,7,8-7HCDF	-	"	1/5	ND-0.0000022
1,2,3,4,7,8,9-7HCDF	-	"	0/5	ND
8OCDF	-	"	0/5	ND
White Suckers (1988)[2]				
2,3,7,8-TCDD	0.00002	0.000002	4/4	0.0000027-0.0000120
2,3,7,8-TCDF	-	0.000002	4/4	0.0000210-0.0000650

ND = not detected
[1] data courtesy of the OMOE/OMNR Sportfish Consumption Program.
[2] data from Sherman et al. (1990).

Table 3.18 Organochlorine concentrations in young-of-the-year spottail shiners collected from Jackfish Bay from 1979 to 1988 (Suns et al. 1991). Values are means (standard deviations) expressed as µg/g.

Year	n	Total Length	Fat (%)	PCBs	DDT	Mirex	Chlordane	BHC	HCB	OCS
Detection Limit				0.02	0.002	0.005	0.002	0.001	0.001	0.001
GLWQA Specific Objective				0.1	1.0	detection	-	-	-	-
1979	7	33-4	2.0 (0.4)	TR	ND	ND	ND	ND	ND	-
1983	7	36-2	4.1 (0.5)	0.089 (0.022)	0.003 (0.001)	ND	ND	0.005 (0.001)	TR	ND
1984	7	31-4	0.7 (0.1)	TR	0.002 (0.001)	ND	ND	ND	ND	ND
1986	3	35-4	2.2 (0.2)	ND	0.002 (0)	ND	ND	ND	0.004(0)	ND
1987	3	45-2	4.2 (0.4)	ND	TR	ND	ND	ND	ND	ND

ND = not detected
NA = not sampled
\- = no objective

of Moberly Bay and the northwestern portions of Jackfish Bay were affected, by 1987 the density of *P. hoyi* had decreased in Tunnel Bay as well as the eastern and central portions of Jackfish Bay.

These trends were similar to those observed by the distribution and number of impaired benthic communities. The extent of communities identified as impaired increased between 1969 and 1975. Between 1975 and 1987 the extent increased further and an additional impaired community was identified. Impaired communities were found to occur in sediments which had the highest mean concentrations of cadmium, copper, lead, zinc and TKN as well as high levels of fibre (loss on ignition). The impact to benthic macroinvertebrates in the Jackfish Bay AOC have been attributed to the Kimberly-Clark mill effluent.

Changes to the structure of the fish community have been mostly related to causes such as over-harvesting, the sea lamprey and the introduction of exotic species. However, recent studies of lake whitefish, longnose sucker and white sucker from Jackfish Bay have revealed several effects which researchers attributed to be due to the mill effluent. These include slower growth, smaller gonads, lower fecundity with age, absence of secondary sex characteristics in males, failure of females to show increase in egg size with age, decreased estradiol and testosterone levels and increased mixed oxidase function activities in comparison to noncontaminated reference fish. The increased MFO activity has been attributed to the presence of organic contaminants such as dioxins, furans and resin acids which are present in the mill effluent. The addition of secondary treatment in October 1989 reduced the toxicity of the effluent, but has not resulted in a reduction of MFO activity in white suckers from Jackfish Bay.

The body burdens of native benthos (*Mysis relicta*), introduced mussels (*Elliptio complanata*) and white suckers from Jackfish Bay indicate a pattern of dioxin and furan bioaccumulation which suggests the mill effluent as the major source. This includes the bioaccumulation of tetrachlorodibenzo-p-dioxins (including the highly toxic 2,3,7,8-TCDD congener) and tetrachlorodibenzofurans, contributed by the effluent, in greater concentrations than the higher chlorinated dioxins, contributed mostly through atmospheric deposition. The higher chlorinated compounds occur in sediment at concentrations comparable or higher than the TCDDs and TCDFs, however, the latter appear to be preferentially accumulated by biota.

Although fish consumption advisories were previously in effect due to mercury and PCB concentrations, these restrictions have been removed. The removal is based on collections during 1989 which indicated that all contaminants were below the Ontario consumption guidelines. However, consumption of lake trout greater than 55 cm may be restricted for consumption due to the sum of dioxins and furans expressed as toxic equivalents of 2,3,7,8-tetrachlorodibenzo-p-dioxin. The only guideline exceedence in either sport fish or young-of-the-year spottail shiners collected in 1989 and 1988, respectively, is the GLWQA Specific Objective for the protection of piscivorous wildlife from PCBs. This objective was exceeded by up to four times by the maximum concentration measured in lake trout collected during 1989.

3.4 BLACKBIRD CREEK

The environmental condition of Blackbird Creek, including Lake A and Moberly Lake, has also been impacted due to its role as effluent receiver for the Kimberly-Clark Canada Inc. mill. The Blackbird Creek system has been utilized since 1948 with the expectation that it would provide some level of natural effluent treatment. As part of this natural treatment system, Lake A was to serve as a settling basin for solids and its capacity would be maintained by regular dredging. However, dredging was not sufficient to remove the large quantities of solids being deposited and, as a result, the lake quickly in-filled. Lake A has since been bypassed and no longer provides any treatment capacity.

3.4.1 Upstream - Downstream Water Quality

During the 1987/88 water quality surveys undertaken by OMOE, Blackbird Creek was sampled at an upstream location (Station 20) close to the mill effluent discharge and a downstream location (Station 5) near its outlet to Moberly Bay. Analyses were undertaken for bacteria, conventional parameters, nutrients, metals, and various organic contaminants including organochlorine pesticides, phenolics and resin and fatty acids (Sherman 1991). The mean, ranges and exceedences of PWQO for these parameters are provided by station and year in Tables 3.19 through 3.23. For the downstream station (Station 5), the tables provide an indication of whether or not mean concentrations increased, decreased or were unchanged relative to the upstream effluent for comparable sample periods. The percent of samples which exceeded the PWQO at the downstream station are also indicated.

Table 3.19a summarizes the data for conventional parameters, nutrients and metals for effluent (Station 20). Table 3.19b provides data for the same parameters for the downstream Blackbird Creek station (Station 5). Of 26 parameters analyzed at Station 5 in 1987, 21 decreased in concentration in the downstream direction. Twelve of these trends were statistically significant ($p < 0.05$). Only pH, magnesium and iron increased from the effluent discharge to the outlet of Blackbird Creek. The trends were similar during 1988 with 22 of 27 parameters showing decreasing downstream trends (10 significantly). Magnesium, alkalinity and pH were the only parameters to increase, and none of these trends were significant. PWQOs were exceeded regularly near the outlet of Blackbird Creek for pH (1987), total phosphorus (1987/88), aluminum (1987/88), iron (1987/88) and zinc (1987/88).

Tables 3.20a and 3.20b summarize the effluent and Blackbird Creek data, respectively, for organochlorine pesticides. Downstream trends for the 21 parameters measured are highly variable with 14 increasing in concentration during 1987 and only 8 increasing during 1988. The lack of a clear trend between upstream and downstream concentrations indicate that the creek does not play a role in either reducing or enhancing the loadings of these contaminants prior to entry into Moberly Bay. Also, the relatively low concentrations suggest the mill effluent is not a major source of organochlorine pesticides, including PCBs, to the AOC. Occasional exceedences of PWQOs for several parameters were recorded, particularly for dieldrin, methoxychlor, endrin, endosulphan I, endosulphan II, endosulphan-SO_4, heptachlor, p,p-DDD, p,p-DDE and p,p-DDT. The source of these contaminants is not apparent.

Resin and fatty acids data are provided in Table 3.21. These parameters are characteristic of effluent derived from bleached kraft paper mills and contribute to effluent toxicity. Eighteen of the 20 acids decrease in concentration from the effluent discharge to the lower portion of Blackbird Creek in 1988. However, none of the differences between upstream and downstream mean concentrations were statistically significant ($p < 0.05$).

Tables 3.22a and b indicate that virtually all phenol compounds decrease in concentration in the downstream direction within Blackbird Creek. Of particular concern are concentrations of 2,3,4,5-tetrachlorophenol, 2,4,6-trichlorophenol and pentachlorophenols which exceed their respective PWQOs within the creek.

Geometric mean densities of total coliform, *Escherichia coli*, *Pseudomonas aeruginosa*, and heterotrophic bacteria for Stations 20 and 5 are provided in Tables 3.23a and b. Geometric means increased in the downstream direction for all four bacterial parameters during 1987. Increases in mean total coliform and heterotrophic bacteria densities were significant ($p < 0.05$). The trends were more variable and not significant during the 1988 surveys. Geometric mean total coliform exceeded the PWQO (1,000 organisms/100 mL) and *Escherichia coli* and *Pseudomonas aeruginosa* exceeded the IJC recommended densities (23 and 1 organisms/100 mL, respectively) for the protection of human bathers during both 1987 and 1988. Increases in the downstream direction indicate that either additional sources of bacteria occur

Table 3.19a Concentrations of conventional parameters, nutrients and metals in Kimberly-Clark (Station 20) effluent samples in 1987 and 1988 (Sherman 1991). All units in mg/L unless otherwise noted.

Parameter	July/Aug 1987				July 1988			
	N	Minimum	Maximum	Mean	N	Minimum	Maximum	Mean
Conventional Parameters (mg/L):								
Calcium	20	39.0	69.0	45.65	17	37.80	119.0	58.11
Magnesium	20	3.9	5.5	4.89	16	4.5	6.0	4.93
Sodium	20	190	360	260.75	17	188	340	252.71
Potassium	20	6.0	20.0	9.81	17	5.1	12.0	9.0
Alkalinity	14	0.0	230.0	75.64	17	47.7	227.9	133.19
Sulphate	20	38.40	112.00	66.32	17	0.00	274.20	89.39
Chloride	21	160	492	362.86	17	224	435	309.35
pH	20	3.2	8.9	5.38	16	6.6	7.9	7.05
Cond25 (umho/cm)	21	1,171	1,970	1,611.19	18	1,203	1,980	1,492.72
Suspended Solids	20	10	120	26	16	14.5	113	37.93
Turbidity (FTU)	20	29	70	38.45	16	10.3	28	19.79
Nutrients (mg/L):								
Total Phosphorus	20	0.12	0.68	0.42	16	0.14	0.74	0.37
Phosphate	8	0.06	0.88	0.35	14	0.03	0.19	0.07
Ammonium	5	0.10	3.20	1.60	14	0.05	0.30	0.15
TKN	20	0.40	3.50	1.89	16	0.85	2.80	2.02
Nitrate	7	0.11	0.46	0.29	11	0.05	0.30	0.19
DOC	20	85	223	173	16	14.3	196	157
Tannins	19	50	200	92.68	16	25	125	64.38
True Colour	20	648	1,870	1,152.85	16	500	1,577	1,128.94
BOD_5	17	80	195	152.06	16	37	242	146.06
Metals (mg/L):								
Aluminum	18	0.34	1.00	0.79	16	0.07	4.70	0.74
Arsenic	21	<0.001	0.003	0.001	16	<0.001	0.002	<0.001
Beryllium	21	-	-	-	16	-	-	-
Cadmium	21	-	-	-	16	-	-	-
Chromium	21	-	-	-	16	0.02	0.41	0.08
Copper	21	-	-	-	16	<0.002	0.11	0.02
Iron	21	0.44	1.20	0.81	16	0.21	1.10	0.55
Mercury (μg/L)	20	<0.01	0.39	0.05	15	<0.01	0.40	0.06
Manganese	21	0.30	0.79	0.51	16	0.30	0.53	0.39
Nickel	21	-	-	-	16	-	-	-
Lead	21	-	-	-	16	-	-	-
Zinc	21	0.07	0.33	0.15	15	<0.005	0.19	0.07

Table 3.19b Concentration of conventional parameters, nutrients and metals in Blackbird Creek (Station 5) water samples in 1987 and 1988 (Sherman 1991). All units in mg/L unless otherwise noted.

Parameter	July/Aug 1987						July 1988						
	N	Minimum	Maximum	Mean	Trend*	%exceed	N	Minimum	Maximum	Mean	Trend*	%exceed	PWQO
Conventional Parameters (mg/L):													
Calcium	22	4.0	55.0	40.84	↓		17	35.20	67.40	52.20	↓		
Magnesium	21	5.0	6.2	5.60	⬆		16	4.6	5.5	5.03	↑		
Sodium	22	120.0	274.0	188.0	⬇		17	134	260	206.41	⬇		
Potassium	22	4.5	11.3	6.72	⬇		17	4.4	9.8	7.67	↓		
Alkalinity	22	8.0	156.0	55.09	↓		17	84.70	204.0	149.45	↑		
Sulphate	22	30.0	79.10	48.27	⬇		17	31.10	91.30	61.70	↓		
Chloride	23	190.0	420.0	291.74	⬇		17	173.0	370.0	257.65	⬇		
pH	22	5.0	7.1	6.33	⬆	59%	16	6.80	7.50	7.20	↑	0%	6.5-8.5
Cond25 (umho/cm)	23	913.0	1,680.0	1,225.04	⬇		17	881.0	1,490.0	1,261.12	⬇		
Suspended Solids	21	10.0	45.0	24.90	↓		16	15.20	40.0	26.07	⬇		
Turbidity (ftu)	22	14.0	36.0	22.09	⬇		16	8.00	30.0	14.81	⬇		
Nutrients (mg/L):													
Total Phosphorus	21	0.13	0.71	0.40	↓	100%	15	0.03	0.43	0.29	↓	93%	0.03
Phosphate	5	0.07	0.15	0.11	↓		15	0.03	0.11	0.06	-		
Ammonium	1	0.50	0.50	0.50	↓	NC	15	0.05	0.20	0.12	↓	NC	
TKN	21	0.48	2.90	1.88	-		16	1.50	2.80	1.98	↓		
Nitrate	6	0.10	1.0	0.27	-		7	0.05	0.20	0.14	↓		
DOC	22	3.20	383.0	113.0	⬇		15	8.20	124.0	98.20	⬇		
Tannins	20	25	90	62.5	⬇		16	25	125	59.25	↓		
True Colour	22	678	1,240	928.0	⬇		16	463	1,412	1,009.94	↓		
BOD (5 Day)	21	30	195	69.5	⬇		15	36	298	75.78	⬇		

Table 19b (Cont'd)

Parameter	July/Aug 1987						July 1988						PWQO
	N	Minimum	Maximum	Mean	Trend*	%exceed	N	Minimum	Maximum	Mean	Trend*	%exceed	
Metals (mg/L):													
Aluminum	17	0.34	1.0	0.60	↓	NC	16	0.07	0.48	0.29	⬇	94%	0.075†
Arsenic	20	<0.001	0.002	<0.001	↓	0%	16	<0.001	<0.001	<0.001	-	0%	0.10
Beryllium	20	-	-	-			16	-	-	-			
Cadmium	20	-	-	-			16	-	-	-			0.0002
Chromium	20	-	-	-			16	0.02	0.08	0.05	↓	0%	0.10
Copper	20	-	-	-			16	-	-	-			0.005
Iron	20	0.56	1.30	0.88	↑	100%	16	0.36	0.61	0.51	↓	100%	0.30
Mercury (μg/L)	22	<0.01	0.03	<0.01	↓	0%	15	0.01	0.13	0.02	↓	0%	0.20
Manganese	20	0.24	0.56	0.38	↓		16	0.21	0.46	0.34	⬇		
Nickel	20	-	-	-			16	-	-	-			0.025
Lead	20	-	-	-			16	-	-	-			
Zinc	20	0.04	0.17	0.10	↓	100%	16	0.01	0.10	0.03	⬇	31%	0.03

* Trend symbols are as follows:
- ↓ decrease from upstream station
- ↑ increase from upstream station
- ⬇ significant decrease from upstream station
- ⬆ significant increase from upstream station
- \- no change from upstream station

NC Percent in exceedence of PWQO not calculated
† PWQO is for a range of pH 6.5 - 9.0

Table 3.20a Concentration of organochlorine pesticide levels in Kimberly-Clark (Station 20) effluent samples in 1987 and 1988 (Sherman 1991). Concentrations are in ng/L.

Parameter	July/Aug 1987				July 1988			
	N	Minimum	Maximum	Mean	N	Minimum	Maximum	Mean
Organochlorine Pesticides (ng/L):								
Aldrin	17	<1.00	<1.00	<1.00	16	<1.00	67.0	5.12
α-BHC	17	<1.00	<1.00	<1.00	16	<1.00	170.00	17.90
b-BHC	17	<1.00	<1.00	<1.00	16	<1.00	1030.00	87.10
γ-BHC	17	<1.00	<1.00	<1.00	16	<1.00	140.00	21.90
α-Chlordane	17	<2.00	<2.00	<2.00	16	<2.00	<2.00	2.00
γ-Chlordane	17	<2.00	<2.00	<2.00	16	<2.00	<2.00	2.00
Dieldrin	17	<4.00	50.00	9.53	16	<4.00	200.00	18.5
DMDT-Methoxychlor	17	<4.00	950.00	138.00	16	<4.00	750.00	71.80
Endrin	17	<4.00	400.00	28.20	16	<4.00	290,00	24.10
Endosulphan-SO4	17	<4.00	170.00	22.50	16	<4.00	160.00	21.50
Endosulphan I	17	<2.00	150.00	17.10	16	<2.00	100.00	17.90
Endosulphan II	16	<4.00	104.00	14.00	16	<4.00	60.00	9.75
Heptachlor epoxide	16	<2.00	<8.00	2.37	16	<2.00	203.00	30.60
Heptachlor	17	<1.00	<1.00	<1.00	16	<1.00	90.00	16.40
Mirex	17	<5.00	<5.00	<5.00	16	<5.00	<5.00	<5.0
Oxychlordane	17	<2.00	<2.00	<2.00	16	<2.00	86.00	13.30
OP-DDT	17	<5.00	<5.00	<5.00	16	<5.00	<5.00	<5.00
Total PCB	17	<20.00	<20.00	<20.00	16	<20.00	<20.00	<20.00
PP-DDD	17	<5.00	<5.00	<5.00	16	<5.00	720.00	87.20
PP-DDE	17	<1.00	<1.00	<1.00	16	<1.00	25.00	3.69
PP-DDT	17	<5.00	155.00	16.20	16	<5.00	160.00	23.80

Table 3.20b Concentration of organochlorine pesticide levels in Blackbird Creek (Station 5) water samples in 1987 and 1988 (Sherman 1991). All units in ng/L.

Parameter	July/Aug 1987					July 1988					PWQO
	N	Minimum	Maximum	Mean	Trend* %exceed	N	Minimum	Maximum	Mean	Trend* %exceed	
Organochlorine Pesticides (ng/L):											
Aldrin	23	<1.00	<10.00	1.74	↑ 0%	15	<1.00	<1.00	<1.00	↓ 0%	1.0
α-BHC	23	<1.00	<10.00	2.13	↑	15	<1.00	40.00	3.60	↓	
b-BHC	23	<1.00	<10.00	1.74	↑	15	<1.00	214.00	29.30	↓	
γ-BHC	23	<1.00	<10.00	1.74	↑	15	<1.00	150.00	27.50	↑	
α-Chlordane	23	<2.00	<10.00	2.35	↑ 0%	15	<2.00	39.00	4.47	↑ 0%	60.0
γ-Chlordane	23	<2.00	<10.00	2.35	↑ 0%	15	<2.00	70.00	10.10	↑ 7%	60.0
Dieldrin	23	<4.00	40.00	8.09	↓ 9%	15	<4.00	40.00	6.40	↓ 0%	1.0
DMDT-Methoxychlor	23	<5.00	520.00	101.00	↓ 26%	15	<4.00	40.00	7.27	↓ 0%	40.0
Endrin	23	<4.00	40.00	6.96	↓ 4%	15	<4.00	96.00	14.90	↓ 13%	2.0
Endosulphan-SO4	23	<4.00	76.00	12.70	↓ 13%	15	<4.00	40.00	6.40	↓ 0%	3.0
Endosulphan I	23	<2.00	106.00	14.20	↓ 13%	15	<2.00	20.00	3.20	↓ 0%	3.0
Endosulphan II	23	<4.00	40.00	7.65	↓ 4%	15	<4.00	80.00	15.90	↑ 13%	3.0
Heptachlor epoxide	22	<2.00	<10.00	2.64	↑ 0%	15	<2.00	3.20	4.65	↓ 0%	1.0
Heptachlor	23	<1.00	<5.00	1.35	↑ 0%	15	<1.00	10.30	25.70	↑ 13%	1.0
Mirex	23	<5.00	10.00	6.96	↑ 4%	15	<5.00	<5.00	0.00	- 0%	1.0
Oxychlordane	23	<2.00	<10.00	2.35	↑	15	<2.00	8.07	19.10	↑	
OP-DDT	23	<5.00	<25.00	5.87	↑ 0%	15	<5.00	15.00	38.70	↑ 7%	3.0
Total PCB	23	<20.00	<100.00	27.00	↑ 0%	15	<20.00	<20.00	0.00	- 0%	1.0
PP-DDD	23	<5.00	<25.00	5.87	↑ 0%	15	<5.00	26.30	66.80	↓ 13%	1.0
PP-DDE	23	<1.00	<5.00	1.17	↑ 0%	15	<1.00	5.00	11.80	↑ 13%	1.0
PP-DDT	23	<5.00	30.00	6.96	↓ 4%	15	<5.00	38.00	128.00	↑ 7%	1.0

* Trend symbols are as follows:
↓ decrease from upstream station
↑ increase from upstream station
\- no change from upstream station

Note: no significant downstream differences for any of these parameters.

Table 3.21 Comparison of resin, aromatic and fatty acid levels in effluent samples and water samples collected from Kimberly-Clark (Station 20) and Blackbird Creek (Station 5) in 1987 and 1988 (Sherman 1991). All units are in µg/L.

Parameter	Kimberly-Clark Effluent (Station 20)				Blackbird Creek (Station 5)					
	July/Aug 1987		July 1988		July/Aug 1987			July 1988		
	N	Mean	N	Mean	N	Mean	Trend*	N	Mean	Trend*
Resin Acids (µg/L):										
Abietic Acid	20	45	17	346	20	13	↓	17	51	↓
Chlorodehydroabietic Acid	20	18	17	14	20	17	-	17	12	↓
Dichlorodehydroabietic Acid	20	13	17	11	20	12	-	17	<10	↓
Dehydroabietic Acid	20	120	17	491	20	75	↓	17	181	↓
Isopimaric Acid	20	35	17	135	20	24	↓	17	49	↓
Levopimaric Acid	20	13	17	95	20	12	-	17	11	↓
Neoabietic Acid	20	12	17	51	20	10	↓	17	12	↓
Palustric Acid	16	9	14	33	14	10	-	17	11	↓
Pimaric Acid	20	22	17	91	20	15	↓	17	54	↓
Sandaracopimaric Acid	20	14	17	35	20	11	↓	17	12	↓
Fatty Acids (µg/L):										
Arachidic Acid	20	21	17	15	20	18	↓	17	11	↓
Capric Acid	20	11	17	10	20	10	-	17	10	-
Dichlorostearic Acid	20	26	17	12	20	18	↓	17	10	↓
Lauric Acid	20	10	17	10	20	10	-	17	10	-
Linoleic Acid	20	44	17	44	20	10	↓	17	10	↓
Linolenic Acid	20	12	17	13	20	11	-	17	10	↓
Myristic Acid	20	10	17	11	20	10	-	17	10	↓
Oleic Acid	20	28	17	50	20	18	↓	17	11	↓
Palmitic Acid	20	28	17	81	20	16	↓	17	43	↓
Stearic Acid	20	25	17	28	20	18	↓	17	21	↓

* Trend symbols are as follows:
↓ decrease from upstream station
↑ increase from upstream station
\- no change from upstream station

Note: no significant differences in downstream concentrations

Table 3.22a Concentrations of polychlorinated phenols in effluent samples in Kimberly-Clark (Station 20) in 1987 and 1988 (Sherman 1991). All units are in ng/L.

Parameter	July/Aug 1987				July 1988			
	N	Minimum	Maximum	Mean	N	Minimum	Maximum	Mean
Polychlorinated Phenols (ng/L):								
2,3,4 trichlorophenol	17	<100	11,000	1,376	17	<100	<1,000	233
2,3,4,5 tetrachlorophenol	17	<20	1,870	307	17	<50	1,820	224
2,3,5,6 trichlorophenol	17	<10	6,150	1,908	17	<50	<500	115
2,4,5 trichlorophenol	17	<50	950	231	17	<50	150	136
2,4,6 trichlorophenol	17	<50	21,000	8,747	16	<50	9,000	4,263
Pentachlorophenol	17	<50	5,250	2,021	17	<50	1,100	434

Table 3.22b Concentrations of polychlorinated phenols in Blackbird Creek (Station 5) water samples collected in 1987 and 1988 (Sherman 1991). All units are in ng/L.

Parameter	July/Aug 1987					July 1988					
	N	Minimum	Maximum	Mean	Trend*	N	Minimum	Maximum	Mean	Trend*	PWQO
Polychlorinated Phenols (ng/L):											
2,3,4 trichlorophenol	18	<100	1,100	157	⬇ 0%	17	<100	275	163	↓ 0%	18,000
2,3,4,5 tetrachlorophenol	18	<20	1,500	255	↓ 6%	17	<50	440	126	↓ 0%	1,000
2,3,5,6 trichlorophenol	17	<50	2,480	612	⬇ 0%	17	<50	<500	76.5	↓ 0%	18,000
2,4,5 trichlorophenol	18	<50	525	139	↓ 0%	17	<50	590	115	↓ 0%	18,000
2,4,6 trichlorophenol	18	1,430	14,000	5,971	↓ 0%	16	<50	24,000	4,929	↑ 6%	18,000
Pentachlorophenol	18	<50	2,465	923	⬇ 67%	17	<50	1,330	320	↓ 12%	500

* Trend symbols are as follows:
↓ decrease from upstream station
↑ increase from upstream station
⬇ significant decrease from upstream station

Table 3.23a. Bacterial densities in effluent samples in Kimberly-Clark (Station 20) in 1987 and 1988 (Sherman 1991). All units are count per 100 mL.

Parameter	July/Aug 1987				July 1988			
	N	Minimum	Maximum	Mean*	N	Minimum	Maximum	Mean*
Bacterial Densities (Cnt/100 mL):								
Total Coliforms	5	<100	300,000	7,096	7	7,000	9,000,000	568,853
Total Coliform (background)	5	<10,000	10,000,000	626,614	0	-	-	-
Escherichia coliform by MPN	5	<3	9	4	7	<3	43	8
Heterotrophic at 20°C	5	<10,000	1,705,000	130,918	1	5,200,000	5,200,000	5,200,00
Pseudomonas aeruginosa	5	<10	200	29	7	<10	800	57

* Geometric Mean

Table 3.23b Bacterial Densities in Blackbird Creek (Station 5) water samples in 1987 and 1988 (Sherman 1991). All units are count per 100 mL.

Parameter	July/Aug 1987					July 1988					
	N	Minimum	Maximum	Mean*	Trend†	N	Minimum	Maximum	Mean*	Trend†	Guide
Bacterial Densities (Cnt/100 mL):											
Total Coliforms	6	1,400,000	9,000,000	3,749,730	⬆	7	28,000	800,000	361,410	↓	1,000‡
Total Coliform (background)	6	14,000,000	38,000,000	17,458,222		0	-	-	-		
Escherichia coliform by MPN	5	23	240	55	↑	7	<3	93	6	↓	23§
Heterotrophic at 20°C	6	3,850,000	11,000,000	7,194,490	⬆	2	3,200,000	6,900,000	4,698,941	↓	
Pseudomonas aeruginosa	5	90	200	113	↑	6	50	<100	49	↓	1§

* Geometric Mean

† Trend symbols are as follows:
- ↓ decrease from upstream station
- ↑ increase from upstream station
- ⬆ significant increase from upstream station

‡ PWQO

§ IJC recommended guidelines

downstream of the mill discharge or the organisms are naturally reproducing. It should be noted that although the density of total coliforms were relatively high, the geometric means at both stations during 1987 were much lower than at the control station.

The concentrations of most conventional parameters, nutrients, metals, phenolic compounds, and resin and fatty acids either show a slight, non-significant decrease or a significant decline in concentrations as the effluent passes through the Blackbird Creek System. This suggests that the creek provides at least some treatment capacity prior to entering Moberly Bay. However, these trends are based on very limited sampling. The large volume of solids and associated adsorbed contaminants within the creek system remain susceptible to movement into Moberly Bay. Heavy rainfall associated with major summer rainstorms and high flows during spring snow melt are events which could lead to significant downstream transport of sediment and associated contaminants. These events have not been monitored or sampled to determine their significance to the transport of contaminants and, hence, the value of the Blackbird Creek System to serve as an effluent treatment system is not accurately known. High concentrations of most parameters in water and sediment of Jackfish Bay, including numerous exceedences of provincial and GLWQA guidelines, indicate that any treatment is very minor.

Fathead minnows (*Pimephales promelas*) were tested with receiving water samples collected during 1986 and 1987 from Station 5 in Blackbird Creek and a control station (Station 713) in Tunnel Bay for 7-day growth tests (Neville, undated). Fathead minnows were also tested for acute toxicity using receiving waters from Blackbird Creek (Station 5) collected in 1987. The samples from Blackbird Creek were found to inhibit the growth of fathead minnows during both years. Significant reductions in larval growth occurred with 30 percent and 10 percent dilutions (using control sample) relative to the control samples. The undiluted Blackbird Creek samples were also acutely lethal with 40 to 90 percent mortality occurring within 5 hours and 100 percent mortality within 24 hours. However, subsequent toxicity testing of effluent samples (Station 20) since the secondary treatment facility was operational (October 1989) indicated that the resultant final effluent is non-lethal in 96-hour laboratory bioassays with rainbow trout (Section 3.3.2.2).

3.4.2 Sediment Quality

There are few data regarding sediment quality in the Blackbird Creek System. In December 1990 and January 1991, Beak Consultants (1991) sampled mill effluent as well as sediment and water in Blackbird Creek and Moberly Lake to determine the toxic load of the system and identify alternatives for remediation. The results of the effluent analyses are presented in Chapter 4.

Sediments from Blackbird Creek immediately downstream of the Lake A bypass and from Moberly Lake were analyzed for 33 chlorophenols, 10 resin acids and 10 fatty acids. All chlorophenol compounds including pentachlorophenol and several tri- and tetrachlorophenol compounds were not detectable in sediments from the creek. Only 4-chlorocatechol (0.5 $\mu g/g$) and 3,4,6-trichlorocatechol (0.7 $\mu g/g$) were detected in Moberly Lake sediments (Beak Consultants 1991).

A total of only 3.3 $\mu g/g$ of fatty acids and 1.4 $\mu g/g$ of resin acids were measured in Blackbird Creek sediments. However, in Moberly Lake, fatty acids ranged from 70 to 308 $\mu g/g$ and resin acids from 55.0 to 128.4 $\mu g/g$ (Beak Consultants 1991). The most abundant resin acids were abietic, monochlorodehydroabietic, dehydroabietic and dichlorodehydroabietic. The Beak study concluded that the sediments of Moberly Lake were considered an "environmental issue" due to their concentrations of resin and fatty acids.

In addition, the Beak study found concentrations of sodium, BOD_5, COD, phenols and TKN to be 10 to 130 times higher in Moberly Lake sediments than in the control station or the upstream Blackbird Creek station. The control station was in Sister Lake which drains via a small tributary into Blackbird Creek. Measured

concentrations in Moberly Lake sediments were: sodium, 2,300 µg/g; BOD_5, 12,900 µg/g; COD, 500,000 µg/g; and TKN, 3,300 µg/g. The TKN concentration exceeded the Provincial Sediment Quality Guideline at the Lowest Effect Level (550 µg/g) but not the Severe Effect Level (4,800 µg/g).

4.0 SOURCES

4.0 SOURCES

The sources of chemicals which impact on water, sediment and biota quality within the Jackfish Bay AOC include one point source and several nonpoint sources. The only point source is the effluent from the Kimberly-Clark Canada Inc. pulp mill located in Terrace Bay. There are no other industrial or municipal dischargers to the AOC.

Nonpoint sources include atmospheric, in-place sediment contamination (from natural sources as well as Kimberly-Clark effluent) and spills. Other potential nonpoint sources such as urban and agricultural runoff, groundwater contamination from waste sites or shipping do not occur in the Jackfish Bay AOC.

Parameters which have been found to exceed provincial or GLWQA guidelines in water (w), sediment (s) or biota (b) within the Jackfish Bay AOC, primarily during the most recent surveys (1987/88), are listed below.

Conventional and Nutrients	Metals	Organics
turbidity (secchi disc) (w)	aluminum (w)	dehydroabietic acid (w)
dissolved oxygen (w)	arsenic (s)	total phenolics (w)
pH (w)	beryllium (w)	pentachlorphenol (w)
total phosphorus (w,s)	cadmium (w,s)	2,3,4,5-tetrachlorophenol (w)
TKN (s)	chromium (w,s)	2,4,6-trichlorophenol (w)
total coliform bacteria (w)	copper (w,s)	oil and grease (s)
fecal coliform bacteria (w)	iron (w,s)	total organic carbon (s)
	manganese (s)	hexachlorobenzene (s)
	mercury (w,s)	total PCBs (s,b)
	nickel (w,s)	dieldrin (w)
	lead (w,s)	methoxychlor (w)
	zinc (w,s)	endrin (w)
		endosulphan I, II and SO_4 (w)
		heptachlor (w)
		p,p-DDD (w)
		p,p-DDE (w)
		p,p-DDT (w)

High concentrations of certain phenolic compounds, resin and fatty acids, and dioxins and furans, for which no guidelines are available, have also been found to contaminate sediments within the AOC. The IJC recommended guidelines for *Pseudomonas aeruginosa* and *Escherichia coli* were also exceeded during the 1987/88 and earlier investigations.

4.1 POINT SOURCES

As noted above, there is only one point source discharger to the Jackfish Bay AOC. This is the Kimberly-Clark Canada Inc. bleached kraft pulp mill.

4.1.1 Mill History and Effluent Treatment Systems

The Kimberly-Clark pulp mill began operations in 1948 as an unbleached kraft mill (Beak 1988). It was expanded in 1972 to a fully bleached two-line kraft mill with capacity increasing from 240 air dried tonnes per day (ADt/d) to 400 ADt/d (Beak 1988). In 1978, a new bleaching and finishing plant was brought on-line, increasing capacity to 1,135 ADt/d. A primary treatment facility incorporating two reactor clarifiers was installed at the time of the 1978 expansion (Beak 1988). Until this time the only treatment was that afforded by the Blackbird Creek System. Table 4.1 provides a chronological history of the mill development and abatement history.

Beginning in 1972, the mill utilized a mercury anode unit to produce chlorine for the bleaching process. Mercury contamination of sediments in Moberly Bay occurred during this time due to loss of mercury from the unit. This process was discontinued in 1978.

The average effluent flow from the mill in 1990 was 94.9 x 10^3 m^3/day. Two process effluent sewers are discharged from the mill: an acid and an alkaline sewer. The alkaline sewer is discharged to the primary treatment system (clarifier) along with the domestic sewage which has undergone aerobic biological treatment in a packaged sewage treatment plant. It is then transferred to a mixing chamber where it mixes with the acid effluent. The acid sewer contains a low amount of suspended solids such that it can bypass the clarifier to go directly to the acid lift station before entering the mixing chamber. In the mixing chamber, the mixed effluents attain a neutral pH before undergoing secondary treatment in the aerated stabilization basin (ASB).

The primary effluent treatment system is comprised of two mechanical screening systems, a coarse bar screen and a travelling screen and a reactor clarifier. The clarifier sludge is de-watered and burned in the power boiler.

The secondary treatment system consists of a settling basin and three cells. This system is also known as the aerated stabilization basin (ASB). Organic material is broken down by aerobic microorganisms in the three cells, with the greatest degradation occurring in the first cell.

From the secondary treatment system, the effluent is discharged into an effluent canal which discharges into the Blackbird Creek system. This system flows for approximately 14 km, by-passing Lake A and passing through Moberly Lake prior to entering Moberly Bay. The effluent usually comprises over 90 percent of the stream flow in Blackbird Creek. One exception occurs during spring run-off when the natural flow almost doubles the volume of the mill effluent flow.

Control Orders are legally-enforceable requirements issued under Section 6 of the *Environmental Protection Act* (OMOE 1991b). They define abatement actions and compliance dates by which actions must be completed. The current Control Order for Kimberly-Clark Canada Inc. was issued on October 23, 1990. Limits imposed by the Control Order requires that the mill effluent not exceed 22.4 tonnes of BOD_5 per day or 30.0 tonnes/day averaged over any 30 consecutive working days; and 11.5 tonnes/day of suspended solids or 7.0 tonnes/day averaged over any 30 consecutive days. Also, when undiluted, the effluent must pass the 96-hour LC_{50} test (i.e., effluent must not be acutely lethal to test fish). As of December 31, 1991, adsorbable organic halides (AOX) are not to exceed 2.5 kg/ADt of bleached kraft pulp (OMOE data files).

Treatment or process changes to further improve effluent quality are not currently planned for the pulp mill. Although the company is investigating means of reducing AOX levels, additional remedial actions at the mill will be contingent on require provided through the MISA and RAP programs.

Table 4.1 Chronological development and abatement history of the Kimberly-Clark Canada Inc. pulp mill, Terrace Bay, Ontario.

1946	•Construction of Terrace Bay pulp mill commenced
1948	•First pulp produced - November 12 •Rated capacity 320 ADMT/D
1958	•Chlorine dioxide added to bleaching circuit
1973	•Stud lumber mill added •Installed new recovery boiler
1975	•Start of expansion to new mill •Second kraft mill to increase rated capacity to 1135 ADMT/D
1977	•Completed construction of mill expansion •New wood room constructed during mill expansion - Dry debarking
1978	•First pulp produced from No. 2 mill - February •Spill pond constructed
1979	•Clarifier installed for alkaline sewer
1981	•Major fire in the digester/blow tank area - October 30 •During the four and one-half month reconstruction period, a number of improvements were made to process control and environmental equipment included: •Installation of a condensate stripper •Installation of turpentine decanter •Installation of NCG collection and destruction system •Construction of domestic sewage treatment plant •Construction of clarifier screening system bypass
1982	•Cooling water recycle system in place in the kiln/causticizing area
1983	•Knot recycle system in place •Conductivity monitoring system installed in the alkaline sewer system
1984	•Spill control system completed in No. 2 Mill •Improved soap recovery program in place •Higher chlorine dioxide substitution in bleacheries •No. 1 Mill dedicated to hardwood •Polymer feed system added to alkaline clarifier •Additional clarifier added to causticizing area for clarification of area wastes •Improvements made to No. 2 brown stock washers
1985	•No. 2 brown stock closure •Spill control system completed for No. 1 Mill •E.O. stage added to No. 2 bleachery •A number of improvements to both bleacheries, including new instrumentation, resulted in a significant reduction in bleachery chemical use and resultant discharges
1985-86	•A number of improvements to No. 1 brown stock washers including: improved soap recovery, foam control and vacuum improvements
1988	•Clarifier hydraulic load reduced
1989	•Secondary treatment completed - October/89
1990	•Bleach plant improvements •Higher chlorine dioxide substitution •Hypochlorite stage replaced with Papricycle Stage •New control system
1991	•Hot water wood Stave replaced •New chip thickness screening plant •New screen rejects system •Chlorine strength analyzers and re-circulation piping installed
Future Plans	
	•12th Digester in #2 mill to be constructed •Company investigating alternative means of bleaching (ex. oxygen delignification, and R8 chlorine dioxide generator

4.1.2 Effluent Quality

4.1.2.1 Regulated Parameters

The quality of effluent from the Kimberly-Clark mill has improved a great deal over the past several years as a result of a number of abatement efforts. These are summarized in Table 4.1. Table 4.2 provides a summary of annual loadings of parameters which are monitored in effluent as well as an indication of the number of monthly exceedences of their OMOE Control Order limits.

The introduction of secondary treatment in October 1989 was the single most significant addition, as demonstrated by the reduction in biochemical oxygen demand (BOD_5). BOD_5 in the effluent was reduced from an annual average of 26,225 kg/d in 1988 to 1,400 kg/d in 1990 (Table 4.2).

Table 4.2 Average annual effluent loadings of monitored pollutants in Kimberly-Clark Canada Inc. effluent and number of monthly exceedences (in brackets for 1986 to 1989 only)*. All loadings in kg/day unless otherwise noted.

	1973	1981	1986	1987	1988	1989	1990†
Flow (m^3/d)	202,600	113,800	110,333	115,000	117,100	109,344	94,900
BOD_5 (t/d)	30,100	30,600	29,550(0)	24,833(NA)	26,225(5)	17,633(0)	1,400
Total Phosphorus	NA	NA	76.35(1)‡	64.63(0)	62 (0)	NA	NA
Suspended Solids	6,700	5,400	5,345(0)	5,568(2)	4,863(0)	3,878(0)	4,100
Toxicity(LC_{50})**	NA	10.0	12.5-45.6	15.1-42.8	11.8-41.4	25.3-51.0	non-lethal

* data taken from OMOE annual Reports on the Industrial Direct Discharges in Ontario (OMOE 1987, 1988, 1989, 1991b).
† Post-secondary treatment, data from OMOE files.
‡ exceedence considered an anomaly as measurement is not consistent with typical mill levels.
** % effluent required to kill 50% of the test fish.

NA Not available

Suspended solids were reduced by 20 percent over the same period, although most of the improvement occurred prior to the secondary treatment system being operational, as shown by the total loadings as well as the elimination of monthly Control Order exceedences.

The secondary treatment system also reduced the toxicity of the effluent. Kimberly Clark effluent is no longer acutely lethal to rainbow trout as discussed in section 3.3.2. However, sublethal effects are still observed.

Total phosphorus is also routinely monitored. Although exceeding the Control Order limit once in 1986 (Table 4.2), it remains consistently below the 1.0 mg/L concentration guideline (Table 3.19a).

4.1.2.2 Effluent Characterization Studies

In addition to the regular self-monitoring program required for the parameters regulated by the Control Order, several effluent characterization studies have been undertaken. These include the July and August 1987 and July 1988 surveys conducted by OMOE at Station 20 (Sherman 1991); the MISA 12 months of effluent sampling from January 1, 1990 to December 31, 1990 (OMOE 1991c); and a three day final effluent survey undertaken by Beak Consultants in December 1990 to January 1991 (Beak Consultants 1991).

The average loadings for four conventional parameters, four nutrients, four resin acids, four chlorinated phenolics and one organochlorine pesticide in samples collected at Station 20 during the OMOE 1987/88 surveys are provided in Table 4.3. Effluent concentrations and downstream characteristics were discussed in detail in Section 3.4. Tables 3.19 through 3.23 in Section 3.4 summarize effluent concentrations.

The data from the 1987/88 OMOE surveys (presented in Tables 3.19 through 3.23 and in Table 4.3) represent effluent conditions prior to the operation of the secondary treatment system. Those parameters which occur in the mill effluent and also exceeded concentration-based water, sediment or biota guidelines in Blackbird Creek (Station 5) or Moberly, Jackfish, or Tunnel Bays are noted in Table 4.3. Loadings are based on a limited period of sampling, however, the average daily loadings for total phosphorus and suspended solids (Table 4.3) are comparable to the annual loadings for 1987 and 1988 (Table 4.2).

As of 1987/88, the mill effluent contributes large average daily loadings of sodium, chloride, sulphate, suspended solids, phosphorus, phosphate, ammonium and TKN. Resin acids contributed to effluent toxicity in 1987/88 (Table 4.2) with average daily loadings ranging from 1 to 43 kg (Table 4.3).

The Municipal Industrial Strategy for Abatement (MISA) program is a strategy aimed at reducing pollutants to Ontario surface waters. It was announced by the Provincial government in 1986 (OMOE 1986), and affects the municipal sector (sewage treatment plants) as well as eight industrial sectors including: electric power generation; industrial minerals; inorganic chemicals; iron and steel; metal mining and refining; organic chemicals; petroleum refining; and pulp and paper. During the recently completed first stage, the industry monitored their wastewater to determine exactly what was in it and at what concentrations. Based on these results, the government is developing abatement regulations. "MISA's ultimate goal, is the virtual elimination of toxic contaminants in municipal and industrial discharges into waterways. The fulfilment of this goal is necessary to reduce the risk of damage to the ecosystem and to protect public health by minimizing the presence of toxics in drinking water, fish and wildlife" (OMOE 1986).

Effluent monitoring for the pulp and paper sector took place from January 1, 1990 to December 30, 1990 (OMOE 1991c). Regulations based on these results are expected in late 1991. Pulp mills in Ontario's four Lake Superior AOCs are the Thunder Bay, Fort William and Provincial Papers Divisions of Abitibi-Price Inc. and Canadian Pacific Forest Products in Thunder Bay; Domtar Inc. in Red Rock (Nipigon Bay AOC); Kimberly-Clark Canada Inc. in Terrace Bay (Jackfish Bay AOC); and James River Marathon Ltd. in Marathon (Peninsula Harbour AOC). The results of the first six months of monitoring for selected parameters from each of these mills is provided in Table 4.4 (OMOE 1991c). Of particular note are the concentrations of AOX (Adsorbable Organic Halide), TKN, cadmium, chromium, nickel, zinc and tetrachlorodibenzo-p-dioxins in effluent from the Kimberly-Clark mill which tend to be the among the highest of all mills located on Lake Superior.

Table 4.5 compares results of analyses of the 2,3,7,8-tetrachlorodibenzo-p-dioxin congener in effluent at ten pulp mills in northwestern Ontario during the 1990 MISA study. Effluent from the Kimberly-Clark Canada Inc. mill had the second highest mean concentration of all ten mills.

Table 4.3 Loadings of effluent at Station 20 in Jackfish Bay 1987/88. All loadings are in kg/d.

Parameter	July/Aug 1987 Mean (# samples) Range (kg/d)	July 1988 Mean (# samples) Range (kg/d)
Conventional:		
Sodium	29,380 (20) 360 - 54,080	29,360 (17) 1,000 - 29,410
Sulphate	23,460 (20) 5,290 - 56,760	12,840 (17) 0 - 38,630
Chloride (unfilt. reactive)	41,370 (21) 21,470 - 187,490	45,780 (17) 23,770 - 170,830
Suspended Solids	4,640 (20) 2,220 - 19,800	4,280 (17) 0 - 12,430
Nutrients:		
Total Phosphorous*	55 (20) 14 - 89	45 (16) 18 - 81
Phosphate	45 (7) 10 - 111	8 (14) 4 - 21
Total Ammonium	199 (5) 12 - 403	18 (14) 6 - 33
Total Kjeldahl Nitrogen*	250 (20) 47 - 452	246 (16) 108 - 395
Resin Acids:		
Abietic Acid	6.7 (20) 1.1 - 42.1	42.9 (17) 9.4 - 307.5
Chlorodehydroabietic Acid	2.4 (20) 1.1 - 5.3	1.8 (17) 1.1 - 3.6
Dichlorodehydroabietic Acid	1.7 (20) 1.1 - 3.3	1.3 (17) 1.1 - 2.3
Dehydroabietic Acid	15.4 (20) 1.2 - 52.0	60.9 (17) 4.1 - 396.7
Chlorinated Phenolics:		
2,4,6 trichlorophenol	1.119 (17) 0.006 - 2.502	0.530 (16) 0.006 - 1.159
Pentachlorophenol*	0.247 (17) 0.008 - 0.593	0.053 (17) 0.006 - 0.121
Phenolics*	13.71 (11) 0.06 - 50.50	- (0) - -
2,4 dichlorophenol	0.38 (20) 0.11 - 2.70	- (0) - -
Organochlorine Pesticide:		
DDT Total*	0.0021 (17) 0.0006 - 0.0194	0.0027 (16) 0.0005 0.0176

* Parameters which exceeded sediment, water or biota guidelines in Blackbird Creek or Moberly, Jackfish or Tunnel Bays prior to 1989.

Table 4.4 Summary of priority pollutants from the pulp mills located on the north shore of Lake Superior. Results are shown as mean values taken from January 1 to June 30, 1990 as part of the Municipal-Industrial Strategy for Abatement (MISA) for process effluent monitoring of the pulp and paper sector.

Parameter	Abitibi - Fort William Division (Thunder Bay)	Abitibi - Thunder Bay Division (Thunder Bay)	Abitibi - Provincial Papers (Thunder Bay)	Canadian Pacific Forest Products (Thunder Bay)	Domtar (Red Rock)	James River-Marathon (Marathon)	Kimberly-Clark (Terrace Bay)
Conventional Parameters: (mg/L)							
AOX				24.29	1.83	55.60	20.49
BOD_5	499.33	607.82	88.08	280.73	165.41	203.67	15.46
DOC	379.43	611.86	62.49				
TKN	2.71	1.73	1.2	1.44	1.80	3.04	4.71
Total Phosphorous	0.30	0.20	0.08	0.67	0.22	0.65	0.51
TSS	31.82	42.67	34.10	92.50	65.59	41.78	44.25
Metals: (mg/L)							
Aluminum	0.52731	1.03561	2.01154	4.47573	3.44545	0.25840	0.46500
Cadmium	0.00022	0.00157	0.00022	0.00067		0.00033	0.00050
Chromium	0.01067		0.00067	0.08077	0.00800	0.01333	0.16333
Copper	0.05233	0.00317	0.05933	0.02483		0.03667	0.00167
Lead	0.00067	0.00347	0.00468			0.02500	0.00500
Mercury				0.00001		0.00068	0.00003
Nickel	0.00133			0.00267		0.00833	0.01333
Silver	0.00083		0.00067	0.00083			
Zinc		0.06045	0.03800	0.14855	0.04227	0.07480	0.08654
Phenols: (µg/L)							
Phenol	21.86	2.25	0.48	30.00	3.26	1.93	
Chlorinated Organics: (ng/L)							
Total TCDD						0.07	0.18
Total TCDF				0.05		0.49	0.36

Table 4.5 Mean and range of concentrations for dioxins and furans in final process effluents from ten pulp mills in northwestern Ontario. Data was collected from January 1 to December 31, 1990 as part of the MISA monitoring program (OMOE 1991c and Smith, OMOE unpublished data).

Mill	Location	Process Type(s)	#	2378-TCDD (pg/L) Mean (Range)	TEQ* (pg/L)	Flow ($10^3 m^3/d$) Mean (Range)	Loading (g TEQ/yr)
Canadian Pacific Forest Products Ltd.	Thunder Bay	Bleached Kraft Sulfite/Groundwood	18	ND (-)	27.0	173	1.710
	Dryden	Bleached Kraft	18	ND (-)	30.5	31	1.010
Boise-Cascade	Kenora	Sulfite/Mechanical	9	ND (-)	11.5	47	0.197
	Fort Frances	Bleached/Kraft Groundwood	23	1.0 (ND-24)	87.6	77	2.440
James River - Marathon	Marathon	Bleached Kraft	18	9.7 (ND-80)	192.0	61	4.275
Abitibi-Price	Thunder Bay	Groundwood	12	ND (-)	24.0	44	0.385
	Prov. Paper	Sulfite/Mechanical	10	ND (-)	0.001	47	0.017
	Fort William	Groundwood	8	ND (-)	0.008	21	0.016
Domtar	Red Rock	Semi-bleached Kraft Groundwood	18	ND (-)	0.029	94	0.00099
Kimberly-Clark	Terrace Bay	Bleached Kraft	18	5.7 (ND-33)	156.0	94	5.350

* TEQs (Toxic Equivalency Factors) based upon OMOE 1985, summed for the various isomers detected in effluent. Zero (0) was substituted for non-detectable concentrations in calculations, hence these values likely underestimate actual discharges.

Table 4.6 provides the concentration data for all priority pollutants detected in the Kimberly-Clark effluent during the first six months of the 1990 MISA monitoring (OMOE 1991c). Average concentrations for those parameters which had nondetectable values may be underestimated because nondetectable concentrations were treated as zero in calculating the mean. Those parameters which occurred in the mill effluent in 1990 and exceeded the concentration-based water, sediment or biota guidelines in Blackbird Creek (Station 5) or Moberly, Jackfish, or Tunnel Bays prior to 1989 are noted in Table 4.4.

In comparison to the concentrations measured during the earlier 1987/88 surveys (Tables 3.19 to 3.23), the mean concentrations of many parameters have decreased. These include several which exceeded guidelines prior to 1989. Mean concentrations of aluminum, BOD_5, mercury, copper, five resin acids, one fatty acid (oleic acid) and pentachlorophenol were lower in the 1990 MISA monitoring than in either the 1987 or 1988 OMOE surveys. Conversely, mean concentrations of chromium, TKN, total phosphorus, total suspended solids and 2,3,4,5-tetrachlorophenol were higher in the more recent 1990 study. Ammonium, zinc and 2,4,6-trichlorophenol mean concentrations were comparable for both periods.

Chlorinated organic compounds, as measured by the Adsorbable Organic Halide (AOX) test, are limited through a Control Order and are to be reduced to (less than/equal to) 2.5 kg/ADT by Dec 31, 1991. Unpublished data reported since January of 1991 indicate that the company is already meeting this requirement.

Dioxins and furans were measured in the effluent during the MISA monitoring study and, as anticipated, the lower chlorinated congeners dominated. Although 2,3,7,8-TCDD was not specifically analyzed, total TCDD was detected in 67 percent of samples with a maximum concentration of 0.79 ng/L (Table 4.6).

Table 4.7 provides the results of a three day effluent sampling for selected nutrients, chlorophenols, and fatty and resin acids in 1990/91 (Beak Consultants 1991). Total phenol concentrations ranged from 9.4 to 18.6 μg/L. Specific isomers of trichlorophenol and pentachlorophenol were detected only at trace levels, well below PWQOs and much less than reported for the first half of 1990 (Table 4.6) or in 1987/88 (Table 3.22). Resin and fatty acid concentrations were also much lower than during 1987/88 (Table 4.7). Most of the fatty acids and all resin acids were not detected in samples collected on December 12. Only four fatty acids were detected at concentration ranging between 0.019 μg/L (oleic acid) and 0.046 mg/L (palmitic acid).

4.1.2.3 Summary

Kimberly-Clark Canada Inc. is currently meeting its Control Order requirements for BOD_5, suspended solids, AOX, total phosphorus and effluent toxicity. The addition of the secondary treatment facility in October 1989 appeared to be particularly efficient with regard to biological oxygen demanding substances, phenolic compounds and resin and fatty acids. Lower effluent concentrations of resin and fatty acids has reduced the toxicity of the effluent (not acutely lethal in 1990) and resulted in lower concentrations of these acids in surface waters of Moberly Bay (1990 survey, Section 3.1). The PWQO for dehydroabietic acid was exceeded in Moberly Bay during 1987/88, however, in 1990, this acid was not detected.

Although significant reductions have been achieved in the loadings of BOD_5 from the Kimberly-Clark effluent, the occurrence of PWQO violations for dissolved oxygen as recently as 1990 (Section 3.1) suggests that further reductions may be required. Alternatively, there may be ongoing contributions of biological oxygen demanding substances, due to historical deposition in the Blackbird Creek System and/or Moberly Bay.

Most of the water, sediment and biota quality data were collected prior to the secondary treatment facility becoming operational and, hence, it is not known if there has been any improvement with regard to ambient guideline exceedences other than dissolved oxygen and dehydroabietic acid. Mean effluent concentrations of

Table 4.6 Ranges and means of priority pollutants detected in process effluent at Kimberly-Clark Canada Inc., Terrace Bay during the first six months of the 1990 MISA monitoring survey (OMOE 1991c). Units are noted for each parameter.

Parameter	N	Minimum	Maximum	Average	FD (%)
2,4,6 trichlorophenol* (μg/L)	6	1.80	8.80	6.75	100
Adsorbable Organic Halide (mg/L)	78	12.20	29.40	20.49	100
Aluminum* (μg/L)	26	330.00	700.00	465.00	100
COD (mg/L)	181	104.00	1,774.40	553.27	100
Chloroform (μg/L)	6	8.30	24.30	14.67	100
Chromium* (μg/L)	6	80.00	300.00	163.33	100
Hydrogen ion* (pH)	181	6.50	8.10	7.60	100
Nickel* (μg/L)	6	10.00	20.00	13.33	100
Nitrate + Nitrite (mg/L)	26	.10	3.23	.41	100
Specific conductance (μsiem/cm)	181	1,000.00	2,600.00	1,836.00	100
Sulphide (mg/L)	6	.01	4.14	.72	100
Total Kjeldahl Nitrogen* (mg/L)	26	2.50	7.30	4.71	100
Total TCDF (ng/L)	6	.21	.66	.36	100
Total phosphorus* (mg/L)	26	.33	.60	.51	100
Total suspended solids (mg/L)	181	14.00	72.00	44.25	100
VSS (mg/L)	25	15.00	77.50	40.52	100
BOD, 5 day, Total Demand (mg/L)	78	ND	42.60	15.46	99
Ammonia plus Ammonium* (mg/L)	26	ND	2.02	.78	96
Zinc* (μg/L)	26	ND	120.00	86.54	96
2,4 dichlorophenol (μg/L)	6	ND	5.10	2.95	83
Octachlorodibenzo-p-dioxin (ng/L)	6	ND	1.90	.49	83
Total H7CDD (ng/L)	6	ND	.05	.02	67
Total PCDF (ng/L)	6	ND	.09	.04	67
Total TCDD (ng/L)	6	ND	.79	.18	67
2,3,4,5 tetrachlorophenol* (μg/L)	2	ND	1.80	.90	50
Dehydroabietic Acid (mg/L)	77	ND	.06	.01	45
2,3,4,6 tetrachlorophenol (μg/L)	3	ND	1.80	.60	33
Abietic Acid (mg/L)	6	ND	.11	.02	33
Mercury* (μg/L)	6	ND	.10	.03	33
Dichlorodehydroabietic Ac. (mg/L)	77	ND	.05	.01	27
2 methylnaphthalene (μg/L)	6	ND	2.90	.48	17
Cadmium* (μg/L)	6	ND	3.00	.50	17
Chlorodehydroabietic Acid (mg/L)	6	ND	.01	.00	17
Copper* (μg/L)	6	ND	10.00	1.67	17
Hexachlorobutadiene (μg/L)	6	ND	.01	.00	17
Lead* (μg/L)	6	ND	30.00	5.00	17
Oleic Acid (mg/L)	6	ND	.01	.00	17
Pentachlorophenol* (μg/L)	6	ND	1.00	.17	17
Pimaric Acid (mg/L)	6	ND	.01	.00	17
Total H6CDF (ng/L)	6	ND	.04	.01	17
Vanadium (μg/L)	6	ND	20.00	3.33	17

FD Frequency above detection limit (%)
ND Not detected.
* Parameters which exceeded sediment, water or biota guidelines in Blackbird Creek or Moberly, Jackfish or Tunnel Bays prior to 1989.

NOTE: Values less than the detection limit are treated as zero.
Minimum, maximum and average values are cited to two decimal places.

Table 4.7 Chemical analysis of final effluent, 1990/91 (Beak Consultants 1991).

Parameter	December 12	January 8	January 23	PWQO
Total Phenols* (μg/L)	18.6	16.0	9.4	1
Sodium (mg/L)	323.7			
Particulate Residue (mg/L)	24.7			
Total Phosphorus* (mg/L)	0.50			
Total Kjeldahl Nitrogen* (mg/L)	4.50			
Total Ammonium* (mg/L)	1.55			
BOD_5 (mg/L)	10.4			
Chlorophenols (ng/L):				
2,4,6 trichlorophenol*	3200†			18,000
2,4,5 trichlorophenol	<50			(Total T3)
2,3,4 trichlorophenol	<100			
2,3,5,6 tetrachlorophenol	180†			1,000
2,3,4,5 tetrachlorophenol*	<50†			(Total T4)
Pentachlorophenol*	80			500
Fatty Acids (μg/L):				
Capric acid	<5			
Lauric acid	<5			
Myristic acid	<5			
Palmitic acid	46			
Stearic acid	24			
Oleic acid	19			
Linoleic acid	<5			
Linolenic acid	<5			
Arachidic acid	<5			
Palustric acid	<5			
Total	89			
Resin Acids (μg/L):				
Pimaric acid	<5			45
Sandaracopimaric acid	<5			(Total @pH7.5)
Levopimaric acid	<5			
Isopimaric acid	<5			
Neoabietic acid	<5			
Abietic acid	<5			
Dehydroabietic acid	<5			
9,10 dichlorostrearic acid	<5			
Chlorodehydroabietic acid	<5			
Dichlorodehydroabietic acid	<5			
Total	<5			

* Parameters which exceeded sediment, water or biota guidelines in Blackbird Creek or Moberly, Jackfish or Tunnel Bays prior to 1989.

† Trace amount.

aluminum, copper and mercury appear to have declined since 1988. However, the mill effluent is likely the main source of most conventional parameters, bacteria, nutrients, metals, organochlorine pesticides and phenolic compounds which have been found to exceed ambient guidelines.

The source of bacteria, particularly *Escherichia coli* and *Pseudomonas aeruginosa*, is of concern especially as these organisms have exceeded recommended health guidelines in Moberly and Jackfish Bays (Section 3.1). They may originate from domestic sewage within the mill.

The origin of organochlorine pesticides in the mill effluent is not known. These chemicals may be derived from logs which are processed in the mill. Contamination of the logs may reflect atmospheric sources including aerial spraying.

4.2 NONPOINT SOURCES

4.2.1 Atmospheric Deposition

Long range transport and atmospheric deposition are a significant pathway of persistent toxic substances into the Great Lakes (Chan and Perkins 1989, Nriagu 1986, 1990). As such, activities relating to research, monitoring and control are identified as an important component of the GLWQA (1978 as revised 1987, Annex 15). Atmospheric contamination of the lakes is poorly understood and quantified. The reason is that "estimation ofatmospheric loadings of organic and inorganic toxic compounds to the Great Lakes requires information on atmospheric and precipitation concentrations, mass transfer coefficients and physical speciation in the atmosphere and water" (Strachan and Eisenreich 1988). Sufficient information for reliable estimates of atmospheric inputs is only available for PCBs and lead (Table 4.8), although less certain estimates have been attempted for other substances.

Even though they receive lower total loadings of lead and PCBs, the upper Great Lakes (Superior, Michigan, and Huron) receive a significantly greater percentage of their total inputs from the atmosphere than from point sources (Table 4.8). This is due to their large surface area and relative lack of local sources.

Table 4.8 PCB and lead loadings to the Great Lakes and the percentage of total loadings attributed to atmospheric pathways (Strachan and Eisenreich 1988)

	PCB		Lead	
	Total Input (kg/d)	% Atmospheric	Total Input (kg/d)	% Atmospheric
Lake Superior	1.66	90	0.66	97
Lake Michigan	1.88	58	1.49	99.5
Lake Huron	1.74	78	1.18	98
Lake Erie	6.90	13	1.55	46
Lake Ontario	6.96	7	1.17	73

Both lead and total PCBs were nondetectable in the Kimberly-Clark effluent during the 1987/88 surveys (Tables 3.19a and 3.20a). During the MISA monitoring study conducted in the first six months of 1990, lead concentrations averaged 5.0 μg/L in effluent, however, it was detected in only 17 percent of samples (Table 4.6). Loadings have not been calculated for the MISA data, thus it is not known what the relative impact of the effluent is in comparison to atmospheric. However, the lead loading shown in Table 4.8 for Lake Superior represents the entire lake whereas the Kimberly-Clark effluent is much more localized with regard to the Jackfish Bay AOC.

Nriagu (1990) noted that "the atmosphere has become a key medium in the transfer of trace metals to remote aquatic ecosystems". In the case of the Great Lakes, he indicated that well over 50 percent of all trace metals were contributed via the atmosphere. Sources to the atmosphere include biogenic, wind-eroded soils and industrial pollution. Although there are no loading estimates available for metals other than lead, Nriagu (1990) identified the atmosphere as an important pathway for vanadium, mercury and cadmium.

Both tetrachlorodibenzofurans (4CDF) and octachlorodibenzo-p-dioxins (8CDD) were detected in sediments collected in Moberly Bay. There was a progression of significant differences in concentration from the mill effluent to stations in Moberly Bay for 4CDF mean values (Table 3.12). This suggests that the effluent was the main source of this congener. However, there were no significant differences between the stations for 8CDD within Jackfish Bay, indicating that the mill was not the source. Some other source, such as atmospheric deposition, may have been responsible for elevated 8CDD levels (Sherman et al. 1990, Section 3.2.5.3).

PAHs were found in sediments of Jackfish Bay (Section 3.2.5.4), at concentrations which are below the Lowest Effect Level of the Provincial Sediment Quality Guidelines. Chan and Perkins (1989) measured the concentration of various PAH compounds in precipitation samples from four locations in the Great Lakes Basin. The closest station to Jackfish Bay was at Sleeping Giant Provincial Park east of Thunder Bay. The concentration profile indicated that the most abundant PAHs at this station were phenanthrene, methylnaphalene, fluorene and pyrene (Chan and Perkins 1989). The PAHs with the highest concentrations in sediment of Jackfish Bay collected during the 1987/88 surveys were pyrene, flouranthene and chrysene (Table 3.14). Methylnaphalene in sediment was not measured and chrysene in precipitation was not measured. However, the concentration pattern of pyrene and flouranthene suggest that atmospheric deposition may account for the PAHs found in sediment in the Jackfish Bay AOC. Chan and Perkins (1989) noted that higher concentrations of PAHs were found in the upper lakes' stations, farther away from the industrial and urban centres in the lower lakes where consumption of fossil fuel is higher. They concluded that the higher PAHs at Sibley in Lake Superior represented localized effects from domestic wood burning. There are no data on emissions of PAH compounds from local sources in the Terrace Bay area with which to determine the significance of these sources to the local atmospheric depositional component.

The only local air quality monitoring data available for the Jackfish Bay AOC consists of the results of a one day survey conducted by the Air Quality Monitoring Branch of OMOE in the vicinity of the Kimberly-Clark Canada Inc. pulp mill (OMOE data files). Five, 30 minute samples were collected on July 25, 1985. The results of this survey indicated that concentrations of total reduced sulphur compounds off company property, downwind of the plant were less than the 30 minute provisional guideline of 0.027 ppm. The total hydrocarbon loadings for five samples taken on the mill property ranged between 168.9 $\mu g/m^3$ and 3,783.2 $\mu g/m^3$. These loadings were mainly comprised of aromatic compounds, primarily 1-isopropyl-4-methylbenzene which ranged between 64.5 and 2,637.0 $\mu g/m^3$. Chloroform was the most dominant chlorinated organic (5.2 to 236.6 $\mu g/m^3$), although it was well below guideline (1,500 $\mu g/m^3$). Since the time of the survey, the hypo stage in the #1 bleachery has been shut down at Kimberly-Clark and chloroform levels are likely much lower (J. Murphy, OMOE, pers. com.).

4.2.2 Contaminated Sediments

Sediment contamination in Moberly, Jackfish and Tunnel Bays was discussed in Section 3.2 and Section 3.4 which presented data for Blackbird Creek and Moberly Lake. These sediments, although contaminated from a variety of sources, also serve as a source of contamination to biota and water. Remedial strategies for restoring beneficial uses within the Jackfish Bay AOC will need to consider the role of these sediments.

The availability and impact of chemicals in sediments with regard to water and biota in this area has not been thoroughly investigated. The only studies carried out to date are those by Beak Consultants (1991) on sediment from Blackbird Creek and Moberly Lake. Preliminary results of this study indicated that sediments from Moberly Lake were lethal to both Hyallela (LC34) and chironomid larvae (LC42). Chironomid growth was also inhibited. The authors concluded that the toxicants in the sediment of this lake would have to be reduced to at least 18 percent of present levels before the sediment would support benthic life (Beak Consultants 1991).

Body burdens of dioxin and furan congeners in benthic fauna (mussels and opossum shrimp) of Moberly Bay suggest that sediment concentrations, particularly of tetrachlorodibenzo-p-dioxins and tetrachlorodibenzofurans, may be impacting the benthos (Section 3.3). In addition, the draft Provincial Sediment Quality Guideline Lowest and Severe Effect Levels are biologically based. Exceedences of these levels results in impairment to the majority of benthic species.

Chromium, copper, iron and nickel concentrations in samples collected in 1987/88 at a station known to be outside the effect of the Kimberly-Clark mill discharge (Station 844) exceeded the Provincial Sediment Quality Guidelines Lowest Effect Levels. In addition, manganese exceeded the No Effect Level. The elevated concentrations of these five metals may, thus, be related to the geology of the area (Section 3.2.4).

However, each of these four metals are also found in the mill effluent. The effluent characterization study undertaken in 1987/88 indicated that chromium was detected in 48 to 100 percent of samples (mean 0.08 mg/L 1988), copper in 14 to 81 percent of samples (0.02 mg/L 1988); iron in 90 to 100 percent of samples (0.55 mg/L 1988); and nickel in 14 to 44 percent of samples (mostly near detection limits) (Table 3.19a). Chromium and copper were also detected in the effluent in 100 and 17 percent, respectively, of samples during the first six months of the 1990 MISA monitoring study (Table 4.6).

4.2.3 Spills

Kimberly-Clark had a Bunker Oil Spill in the mid-1970s which spread into Moberly Bay. This incident may explain the presence of oil in sediments at stations in Moberly Bay during the 1987 biological surveys (Beak Consultants 1988). The oil was not observed during the 1975 surveys.

Spill and effluent bypass events for 1989, 1990 and 1991 (to mid-September) are listed in Table 4.9. The date, substance spilled, amount of substance (where available) and medium spilled to is indicated.

Land spills are not generally a concern with regard to contamination of the Jackfish Bay AOC as the mill is located outside of the AOC. The only concern would be land based spills which may subsequently reach the effluent canal which connects to Blackbird Creek. Sulphuric acid is the substance most commonly spilled on the mill site.

Gaseous leaks occur and include blow tank gases and digester gases. It is not known which chemicals are vented with these incidents or whether they impact the AOC. Based on the records available (Table 4.9), this does not appear to be a significant concern.

Table 4.9 Spills and effluent bypasses at the Kimberly-Clark Canada Inc. mill during 1989, 1990 and 1991 (OMOE data files).

Date	Substance	Location
1989		
January 27	? tank car spill	land
February 14	chloride gas leak	air
February 21	effluent bypass of clarifiers	water
May 4	soap spill	water
June 13	fuel spill - vehicle accident	land
July 4	black liquor caustic sewers	water
July 13	diesel fuel (114 L)	water
August 8	acid line leak	land
August 8	venting blow tank	air
September 29	discharge to effluent ditch	water
December 29	sulphuric acid (1,300 L)	land
1990		
January 24	venting blow tank	air
January 25	digester cooking gases vented	air
March 19	digester cooking gases vented	air
December 13	sulphuric acid (910 L)	land?
June 13	diesel spill (100 L)	?
August 23	lime powder (15 tonnes)	land
1991		
January 26	alkaline & acid sewers bypass	water
March 6	acid sewer effluent bypass	water
March 14	acid sewer effluent bypass	water
April 20	sulphuric acid (675 L)	land
April 28	acid sewer effluent bypass	water
May 21	acid sewer effluent bypass	water
July 1	sulphuric acid (230 L)	land

Table 4.9 (Cont'd)

Date	Substance	Location
July 7	alkaline & acid sewers bypass	water
July 8	acid sewer effluent bypass	water
July 16	alkaline sewer bypass	water
July 30	alkaline sewer bypass	water
August 2	foam spill	land
August 12	alkaline & acid sewers bypass	water
August 18	alkaline & acid sewers bypass	water
September 8	acid sewer partial bypass	water

Flows in the acid and alkaline sewers, on occasion, bypass the treatment system resulting in untreated effluent reaching Blackbird Creek. As of September 8, there were 12 bypass events during 1991 (Table 4.9). These events were primarily due to equipment failures (O-Rings, seized valves) and power outages which shut down the pumping equipment (P. Jordan, OMOE, pers. com.). Because the volume of effluent which bypasses the system is not known, it is not possible to determine the impact of these events on the AOC. However, it is expected that these events contribute to contamination of Jackfish Bay and, hence, their occurrence should be minimized.

5.0 ENVIRONMENTAL CONCERNS/USE IMPAIRMENT

5.0 ENVIRONMENTAL CONCERNS/USE IMPAIRMENT

5.1 INTRODUCTION

The objective of this chapter is to summarize the use impairments and water, sediment and biota quality problems described in Chapter 3 (Environmental Conditions). Annex 2 of the Great Lakes Water Quality Agreement of 1978, as amended in 1987, defines 'Impairment of Beneficial Use(s)' as "...a change in the chemical, physical or biological integrity of the Great Lakes System sufficient to cause and of the following:

- (i) Restrictions on fish and wildlife consumption;
- (ii) Tainting of fish and wildlife flavour;
- (iii) Degradation of fish and wildlife populations;
- (iv) Fish tumours or other deformities;
- (v) Bird or animal deformities or reproduction problems;
- (vi) Degradation of benthos;
- (vii) Restrictions on dredging activities;
- (viii) Eutrophication or undesirable algae;
- (ix) Restrictions on drinking water consumption, or taste and odour problems;
- (x) Beach closings;
- (xi) Degradation of aesthetics;
- (xii) Added costs to agriculture or industry;
- (xiii) Degradation of phytoplankton and zooplankton populations; and
- (xiv) Loss of fish and wildlife habitat."

Several of these use impairment categories are divided into subcategories for discussion purposes in this chapter to more clearly define the scope of the problems in the Jackfish Bay AOC. For example, 'restrictions on fish and wildlife consumption' is divided into 'restrictions on fish consumption' and 'restrictions on wildlife consumption'.

A determination as to whether a specific use impairment exists in the Jackfish Bay AOC was made using the Listing/Delisting Guidelines for Great Lakes Areas of Concern (IJC 1991) in conjunction with applicable standards, guidelines and objectives where available. In the absence of standards, guidelines or objectives, impairment status is based on best professional judgement from the evidence available. The status of beneficial uses as well as exceedences of ambient standards, guidelines and objectives are summarized in Table 5.1.

5.2 USE IMPAIRMENTS

5.2.1 Restrictions on Fish and Wildlife Consumption

5.2.1.1 Restrictions on Fish Consumption: requires assessment

The 1989 "Guide to Eating Ontario Sport Fish" listed fish consumption restrictions for lake trout longer than 45 cm due to mercury concentrations between 0.5 and 1.0 $\mu g/g$ and/or PCBs greater than 2.0 $\mu g/g$. The 1991 guide identified consumption of lake trout up to 65 cm in length as unrestricted with regard to mercury and PCB concentrations. The consumption of whitefish, cisco and white sucker to 45 cm in length was also unrestricted. However, the guide indicates that consumption of lake trout greater than 55 cm could be restricted due to concentrations of dioxins and furans expressed as toxic equivalents of 2,3,7,8-tetrachlorodibenzo-p-dioxin.

Table 5.1 Summary of impairments to Great Lakes Water Quality Agreement beneficial uses within the Jackfish Bay Area of Concern. Impairment status is defined as impaired (I), not impaired (NI) or requires further assessment (A) and is based on data collected during from 1987 to 1990.

GLWQA Impairment of Beneficial Use	Status of Impairment	Conditions In Jackfish Bay
Restrictions on Fish and Wildlife Consumption		
Restrictions on Fish Consumption	A	The 1991 "Guide to Eating Ontario Sport Fish" notes that the consumption of lake trout greater than 55 cm in size may need to be restricted due to concentrations of dioxins and furans expressed as toxic equivalents to 2,3,7,8-tetrachlorodibenzo-p-dioxin.
Consumption of Wildlife	NI	No restrictions exist
Tainting of Fish and Wildlife Flavour	NI	There have been no reports of tainting by the public or by fisheries/wildlife personnel
Degradation of Fish and Wildlife Populations		
Dynamics of Fish Populations	I	Lake trout populations have declined since the mid 1950s for a number of reasons including the accidental introduction of sea lamprey, the start-up of the Kimberly-Clark mill, over-harvesting and the introduction of exotic fish species. Blackbird Creek fish populations have been totally eliminated as a result of the pulp mill effluent. Similarly, fish populations in Moberly Bay, in the vicinity of Blackbird Creek, have been severely reduced.
Body burdens of Fish	I	White suckers have bioaccumulated TCDDs and TCDFs from water and sediment contaminated by the mill effluent. Lake trout have low concentrations of mercury, hexachlorobenzene and several chlorinated pesticides. The GLWQA Specific Objective for the protection of piscivorous wildlife from PCBs was exceeded in lake trout collected in 1989.
Dynamics of Wildlife Populations	A	Blackbird Creek may attract wildlife during the spring months as the moderating influence of warm creek water tends to accelerate greening of creek side vegetation. Moose activity in particular appears to be abnormally high along Blackbird Creek during the spring. There are no data on possible impacts to wildlife populations due to contaminants within the AOC.
Body burdens of Wildlife	A	Bioaccumulation of contaminants in wildlife may be occurring in portions of Jackfish Bay and the Blackbird Creek system, however, there are no data on contaminant burdens in wildlife. CWS plans a survey of gull populations for completion in 1993.

Table 5.1 (Cont´d)

GLWQA Impairment of Beneficial Use	Status of Impairment	Conditions In Jackfish Bay
Fish Tumours and Other Deformities	I	Although incidences of external fish tumours or other deformities have not been reported, white suckers collected from Jackfish Bay in the summer of 1988, prior to secondary treatment, had an abnormal incidence of liver neoplasms (cancers). Also, greater than 20 percent of lake whitefish had unexplainable external lesions which may be associated with pollutants contributed from mill effluent. A study of tumours in white suckers was conducted by OMOE in 1988 and results are pending.
Bird and Animal Deformities or Reproductive Problems	A	Incidents of bird or animal deformities have not been reported in the AOC. However, indications of reproductive dysfunction in white sucker, longnose sucker and lake whitefish populations in the Jackfish Bay AOC have been reported. CWS plans a survey of gull populations for completion in 1993.
Degradation of Benthos		
Dynamics of Benthic Populations	I	The benthic fauna have been impacted in Moberly, Jackfish and Tunnel Bays as shown by the presence of impaired communities which have increased in number and extent between 1969 and 1987. During this period, pollution intolerant species (<u>Pontoporea hoyi</u>) have decreased in density and extent whereas pollution tolerant species (tubificids) have increased in density and extent. Sediments in Moberly Lake are acutely toxic to benthic fauna.
Body burdens of Benthic Organisms	I	Opposum shrimp (<u>Mysis relicta</u>) and introduced caged mussels (<u>Elliptio complanata</u>) collected in Moberly Bay had a dioxin and furan congener pattern similar to that of the mill effluent. 2,3,7,8-tetrachlorodibenzofuran was the dominant isomer in the shrimp with traces of other congeners including 2,3,7,8-tetrachlorodibenzo-p-dioxin.
Restrictions on Dredging Activities	I	Sediments in the Jackfish Bay AOC, particularly within Moberly and Jackfish Bays contain concentrations of several contaminants which exceeded OMOE Open Water Dredged Material Disposal Guidelines and/or Provincial Sediment Quality Guidelines as of 1987/88. These include oil and grease, total organic carbon, TKN (1990), total phosphorus, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, hexachlorobenzene and total PCBs.
Eutrophication or Undesirable Algae	NI	No nuisance algal growths have not been reported.

Table 5.1 (Cont'd)

GLWQA Impairment of Beneficial Use	Status of Impairment	Conditions In Jackfish Bay
Restrictions on Drinking Water Consumption or Taste and Odour Problems Consumption, Taste and Odour Problems	NI	Drinking water for the Town of Terrace Bay is obtained from Lake Superior west of Jackfish Bay. There have been no consumption restrictions or reported taste and odour problems for treated drinking water. However, cottages are located in the old community of Jackfish, on Jackfish Bay. On occasion, the effluent drifts in this direction, making nontreated water unsuitable for consumption.
Beach Closings	NI	Bacterial densities have periodically been elevated in the vicinity of the Terrace Bay Beach as a result of the mill discharge, however, this condition has not led to beach closings. There are no other public beaches within the Jackfish Bay AOC.
Degradation of Aesthetics	I	Conditions have improved since the early 1970s, however, concerns continue to be expressed regarding the presence of foam and dark colour in Blackbird Creek and Moberly Bay.
Added Cost to Agriculture and Industry	NI	There are no agricultural or industrial activities which utilize water from the Jackfish Bay AOC.
Degradation of Phytoplankton and Zooplankton Populations	NI	There are no widespread effects within the AOC although community structures are likely altered in the immediate area of the discharge. No detailed information exists.
Loss of Fish and Wildlife Habitat	I	Major lake trout spawning grounds were located in Moberly Bay and along the shore of Lake Superior adjacent to Jackfish Bay and were impaired due to physical alteration (deposition of organic matter) and chemical contamination of sediments. Lake whitefish spawning grounds were identified along Lake Superior's shore immediately east and west of Jackfish Bay. The quality and use of these shoals has not been assessed. Blackbird Creek was noted as a brook trout stream prior to the start-up of the mill in 1948.

As of 1991 fish consumption restrictions were in place for Jackfish Lake due to mercury (yellow perch) and mercury and/or PCBs (northern pike and walleye). However, this lake is considered to be outside the influence of the mill effluent and, hence, mercury concentrations >1.5 μg/g in yellow perch between 35 and 45 cm in length is likely due to natural background sources.

5.2.1.2 Restrictions on Wildlife Consumption: not impaired

There are currently no restrictions for the consumption of wildlife form the Jackfish Bay AOC.

5.2.2 Tainting of Fish and Wildlife Flavour: not impaired

No reports of tainted fish or wildlife by the public or the fisheries/wildlife personnel.

5.2.3 Degradation of Fish and Wildlife Populations

5.2.3.1 Dynamics of Fish populations: impaired

Blackbird Creek fish populations have been totally eliminated as a result of the pulp mill effluent. Similarly, fish populations in Moberly Bay, in the vicinity of Blackbird Creek, have been severely reduced. Prior to installation of secondary effluent treatment by the mill, toxicity tests on surface waters up to 1.5 km from the creek mouth resulted in 100 percent fish mortality. Results from toxicity testing since this time indicated that mill effluent is no longer acutely lethal.

Degraded water quality, harvesting, the sea lamprey and introduction of exotic fish species have directly depressed fisheries production in Jackfish Bay. Species diversity and densities in the northern portion of Moberly Bay are among the lowest found in Lake Superior. The zone of influence, which radiates south from the mouth of Blackbird Creek, has diminished fisheries potential in the entire Jackfish Bay area, although the degree of impact has not been determined.

5.2.3.2 Body Burdens of Fish: impaired

Lake trout collected in 1989 had low concentrations of mercury, hexachlorobenzene, p,p-DDE, α- and τ-BHC, α- and τ-chlordane, p,p-DDD, toxaphene, 2,3,7,8-TCDD (0.0000029-0.0000113 μg/g) and 2,3,7,8-TCDF (0.000020-0.000058 μg/g). White suckers collected during 1988 also had low concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF. The GLWQA Specific Objective for the protection of piscivorous wildlife were exceeded by maximum concentrations of total PCBs (0.44 μg/g).

5.2.3.3 Dynamics of Wildlife Populations: requires assessment

Blackbird Creek may attract wildlife during the spring months as the moderating influence of warm creek water tends to accelerate greening of creek side vegetation. Moose activity in particular appears to be high along Blackbird Creek during the spring. There are no data on possible impacts to wildlife populations due to contaminants within the AOC.

5.2.3.4 Body Burdens of Wildlife: requires assessment

Bioaccumulation of contaminants in wildlife may be occurring in portions of Jackfish Bay and the Blackbird Creek system, however, there are no data on contaminant burdens in wildlife. CWS plans a survey of gull populations for completion in 1993.

5.2.4 Fish Tumours or Other Deformities: impaired

Incidents of external fish tumours or other deformities have not been reported. However, the induction of MFO activity in white suckers collected from Jackfish Bay in the summer of 1988, prior to secondary treatment, was correlated with an "abnormal incidence of liver neoplasms (cancers)". Also, greater than 20 percent of lake whitefish caught in Jackfish Bay during August 1989 and August/September 1990 had unexplainable external lesions which did not appear to be related to predatory attack or infection. The presence of these lesions in an isolated, unpopulated bay which has received large volumes of pulp mill effluent, as well as the absence of reports of similar wounding in other lake whitefish, suggested to the authour that there may be an association between the lesions and the discharge of bleached kraft mill effluent.

Research is continuing on the sublethal effects of mill effluent on fish, as well as the cause of the skin lesions on lake whitefish. A study of tumours in white suckers was undertaken in 1988 by the Water Resources Branch of OMOE. Results are pending.

5.2.5 Bird or Animal Deformities or Reproduction Problems: requires assessment

Bird or animal deformities have not been found in the Jackfish Bay AOC, nor have reproduction problems been specifically reported. However, reproductive dysfunction in white sucker, longnose sucker and lake whitefish populations in the Jackfish Bay AOC have been reported. Results from research into the sublethal effects of the pulp mill effluent indicated that these fish grow more slowly than reference fish, have smaller gonads, lower fecundity with age, an absence of secondary sex characteristics in males, failure of females to show an increase in egg size with age, reduced serum estradiol and testosterone concentrations, and greater hepatic mixed-function oxidase (MFO) activity.

A study to determine whether or not herring gulls in the Jackfish Bay AOC have deformities or experience reproductive problems is currently underway by the Canadian Wildlife Service. Results from this study will need to be evaluated when available.

5.2.6 Degradation of Benthos

5.2.6.1 Dynamics of Benthic Populations: impaired

The benthic fauna of the Jackfish Bay AOC have been impacted as a result of the mill effluent discharged through Blackbird Creek. Densities of benthic macroinvertebrates tend to be lowest along the western portion of Moberly and Jackfish Bays due to the influence of the effluent plume from Blackbird Creek. Between 1969 and 1987, maximum densities of pollution tolerant organisms (tubificids) increased by more

than six times while densities of pollution intolerant organisms (*Pontoporeia hoyi*) decreased dramatically. During this period the extent of tubificids also increased in concert with a decrease in the extent of *P. hoyi*. Whereas in 1969 only the central portion of Moberly Bay and the northwestern portions of Jackfish Bay were affected, by 1987 the density of *P. hoyi* had decreased in Tunnel Bay as well as the eastern and central portions of Jackfish Bay.

These trends were similar to those observed by the distribution and number of impaired benthic communities. The extent of communities identified as impaired increased between 1969 and 1975. Between 1975 and 1987 the extent increased further and an additional impaired community was identified. Impaired communities were found to occur in sediments which had the highest mean concentrations of cadmium, copper, lead, zinc and TKN as well as high levels of fibre (loss on ignition). The impact to benthic macroinvertebrates in the Jackfish Bay AOC have been attributed to the Kimberly-Clark mill effluent.

Although there have been no benthic surveys of Blackbird Creek, the toxicity of sediments in Moberly Lake indicates that the sediment is acutely lethal to certain benthic species and is likely severely impaired.

5.2.6.2 Body Burdens of Benthic Organisms: impaired

The body burdens of native benthos (*Mysis relicta*) and introduced mussels (*Elliptio complanata*) from Jackfish Bay indicate a pattern of dioxin and furan bioaccumulation which suggests the mill effluent as the major source. This includes the bioaccumulation of tetrachlorodibenzo-p-dioxins and tetrachlorodibenzofurans. Concentrations of the highly toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin congener in *M. relicta* were 0.000009 $\mu g/g$. Concentrations of tetrachlorodibenzofurans ranged from 0.000034 $\mu g/g$ in introduced mussels to 0.000048 $\mu g/g$ in *M. relicta.*

5.2.7 Restrictions on Dredging Activities: impaired

Dredging operations have not been undertaken in the Jackfish Bay AOC. However, the sediments of Jackfish Bay, especially Moberly Bay, contain levels of oil and grease, total organic carbon, total phosphorus, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, hexachlorobenzene and total PCBs which exceeded the OMOE Open Water Dredged Material Disposal Guidelines and/or the Provincial Sediment Quality Guidelines Lowest Effect Levels in 1987/88. TKN measured in Moberly Lake sediments during 1990 also exceeded the PSQG Lowest Effect Level. In addition, high concentrations of certain phenolic compounds, resin and fatty acids, and dioxins and furans, for which no guidelines are available, contaminate sediments within the AOC.

5.2.8 Eutrophication or Undesirable Algae: not impaired

There are no records or observations of nuisance algal growths in Jackfish Bay.

5.2.9 Restrictions on Drinking Water Consumption or Taste and Odour Problems: not impaired

The Town of Terrace Bay acquires its drinking water from Pumphouse Bay on the north shore of Lake Superior. There have been no consumption restrictions, or taste and odour problems reported with the treated drinking water. Cottages are located in the old community of Jackfish, on Jackfish Bay. On occasion, the effluent plume drifts in this direction, making nontreated water unsuitable for consumption.

5.2.10 Beach Closings: not impaired

Bacteria levels have periodically been elevated in the vicinity of the Terrace Bay beach as a result of the mill discharge, however, this condition has not led to beach closings. There are no other public beaches within the Jackfish Bay AOC. However, exceedences of the fecal and total coliform PWQO have occurred as recently as 1987/88 and the IJC recommended guidelines for *Pseudomonas aeruginosa* and *Echerichia coli* were exceeded within Moberly and Jackfish Bays.

5.2.11 Degradation of Aesthetics: impaired

Mill effluent flow in Blackbird Creek and into Jackfish Bay has deteriorated the aesthetic value of the entire system. Re-routing the effluent away from the highway during the early 1970s has improved the situation but concerns are still expressed. Although the area's scenic beauty, sheltered waters and the wreck of the Rappahanock represent an attraction for boaters and divers, the area receives limited recreational use due to the mill discharge and, to a lesser extent, limited access.

5.2.12 Added Cost to Agriculture or Industry: not impaired

When additional costs are required to treat water prior to use for agricultural or industrial purposes, this use category is considered to be impaired. There are no agricultural or industrial activities which utilize water from the Jackfish Bay AOC.

5.2.13 Degradation of Phytoplankton and Zooplankton Populations: not impaired

There are no widespread effects within the AOC although community structures are likely altered in the immediate vicinity of the discharge. No detailed information exists.

5.2.14 Loss of Fish and Wildlife Habitat: impaired

Fish habitat in Jackfish Bay has not been fully described or mapped, nor has the relationship of various habitat types to fish production been evaluated. However, it is known that industrial pollutants have destroyed or significantly altered fisheries habitat in portions of Jackfish Bay.

Blackbird Creek no longer provides suitable habitat for most aquatic life and may affect the surrounding terrestrial habitat. The mill discharge into Jackfish Bay has degraded bottom sediments, fish habitat and potential spawning grounds. Organic sludge deposits cover most of the natural sediments in Moberly Bay. There are no data regarding the possible loss of wildlife habitat, particularly along the Blackbird Creek System.

6.0 PUBLIC INVOLVEMENT

6.0 PUBLIC INVOLVEMENT

The four Areas of Concern on the Canadian shore of Lake Superior (Peninsula Harbour, Jackfish Bay, Nipigon Bay and Thunder Bay) have been grouped together as the "North Shore of Lake Superior Remedial Action Plans". Although RAPS are being developed separately for each, a single logo was designed for the four Areas of Concern.

6.1 ACTIVITIES TO DATE

The initial step in the public consultation program was identifying potential participants in order to establish a mailing list. The list included representatives from industry, government, labour, fisheries, environment, recreation, education and the general public.

The next step was to develop general information campaign material to promote the RAP. Materials included brochures, buttons, refrigerator magnets and presentation folders. In addition, a toll-free telephone number was set up for interested individuals to call for further information on the program. All people on the mailing list were contacted by letter to inform them about the RAP process, were provided with a copy of the RAP brochure and were invited to open houses organized as a "kick-off" for the program.

The Jackfish Bay open house was held in the Terrace Bay Recreation Centre on December 1, 1988. Materials developed for the open house included a mobile display, status reports and brochures. Advertisements were placed in the local and Thunder Bay newspapers (Appendix 6.1). Approximately 65 people attended the session. They were provided with information on the RAP process, the opportunity to become involved in the Jackfish Bay RAP and the importance that the federal and provincial governments place on public participation. Attendees were invited to sign a register and were added to the mailing list.

After the open house, all people on the mailing list received letters informing them of the success of the open house. The next step in the public consultation program was the formation of a public advisory committee (PAC). Suggestions as to representation on the PAC were solicited. A number of volunteers and nominations were received and the PAC was formed.

The thirteen PAC members include representatives from the public, Kimberly-Clark of Canada, Ltd., Charter Boat Services, the mill union, Jackfish Lake Cottagers, the Township of Terrace Bay, Ducks Unlimited, Minnova Mines, and the Ontario Underwater Council.

The purpose of the PAC is as follows: (1) act as a focal point for public consultation and thereby allow effective dissemination of information on the RAP process and environmental conditions; (2) provide an additional level of review for RAP documents and remedial options; (3) provide an efficient and effective means of ensuring stakeholder input as the RAP is being developed; and (4) provide a basis for broad community support for RAP implementation. The ultimate goal of the public involvement program is to ensure that the plan responds to community needs and enjoys a high level of community support for implementation.

The introductory PAC meeting was held on May 9, 1989 in Terrace Bay. Subsequent meetings were held monthly (Appendix 6.2). In addition, a tour of Jackfish Bay was conducted on June 22, 1989 a tour of Lake A was conducted on July 13, a mill tour was held on October 19, 1989 and a MISA presentation to all four North Shore of Lake Superior PACs was held on November 25, 1989.

PAC members were provided with a variety of information including PAC Terms of Reference (Appendix 6.3), a listing of library references for information on Lake Superior, relevant articles from the IJC publication "Focus", and summaries of available data and reports on Peninsula Harbour environmental

conditions. They were also given copies of *The Great Lakes Water Quality Agreement, First Report under the 1987 Protocol to the 1978 Great Lakes Water Quality Agreement, A Citizens' Guide to the Great Lakes Water Quality Agreement,* and various other documents.

On March 22-24, 1990, the "Making a Great Lake Superior" conference was held in Thunder Bay. This event brought together RAP teams and PACs from Ontario's, Minnesota's, Wisconsin's and Michigan's Lake Superior Areas of Concern, as well as, scientists, resource managers, industry people and environmentalists from Canada and the U.S. The conference provided an excellent opportunity to learn and to share thoughts and ideas on the clean up of Lake Superior and on the RAP process.

As part of the RAP process, the PAC developed a set of Water Use Goals (WUGs) (Appendix 6.4) which they presented to the public in September of 1990 (Appendix 6.4). A booth was set up at the Terrace Bay Fall Fair in order to illustrate the WUGs, and was manned by both PAC members and Environment Ontario staff. In addition, the WUGs and a questionnaire was mailed out to all households in Terrace Bay. Public comment from both the booth and the mail-out was incorporated into the finalized WUGs.

On March 23, 1991, after Stage One completion by all four northshore PACs, a remedial options workshop was held in Thunder Bay to introduce PAC members to Stage Two of the RAP process, and to begin introducing remedial options for rehabilitating AOCs.

Since the inception of the RAP process, public speaking engagements by PAC members and Environment Ontario RAP staff have been ongoing. Talks have been given to school groups and special interest groups, and displays on the RAP program have been set up at a variety of functions.

7.0 REFERENCES

7.0 REFERENCES

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GLOSSARY, ACRONYMS AND UNITS OF MEASURE

COMMONLY USED TERMINOLOGY

Measurements and Units

μg/g	=	micrograms per gram	=	parts per million (ppm)
mg/L	=	milligrams per litre	=	parts per million (ppm)
μg/L	=	microgram per litre	=	parts per billion (ppb)
ng/L	=	nanogram per litre	=	parts per trillion (ppt)
pg/L	=	picograms per litre	=	parts per quadrillion (ppq)
mg/kg	=	milligram per kilogram	=	parts per million (ppm)
μg/kg	=	microgram per kilogram	=	parts per billion (ppb)
ng/kg	=	nanogram per kilogram	=	parts per trillion (ppt)
L/d	=	litres per day		
m^3/d	=	cubic metres per day		
kg/ann (kg/yr)	=	kilograms per year		
t/ann (kg/yr)	=	tonnes per year		
μs/cm	=	microsiemens per centimetre (conductivity)		
mgd	=	millions of gallons per day		
cfs	=	cubic feet per second		

ACRONYMS

AOC	Area of Concern: An area recognized by the International Joint Commission where water uses are impaired or where objectives of the Great Lakes Water Quality Agreement or local environmental standards are not being achieved.
AOX	Adsorbable organic halides, including chlorinated organics.
BOD	Biochemical Oxygen Demand: The amount of dissolved oxygen required for the bacterial decomposition of organic waste in water. Obtained by measuring the amount of oxygen consumed by a sample under controlled conditions over a specified time period.
COA	Canada-Ontario Agreement Respecting Great Lakes Water Quality: The 1986 agreement whereby the governments of Canada and Ontario recognize their shared responsibility to maintain the aquatic ecosystem of the Great Lakes Basin.
COD	Chemical Oxygen Demand: The amount of oxygen required to completely oxidize any oxidizable compounds present by chemical reagents.
DDT	Dichlorodiphenyltrichloroethane: A widely used, very persistent pesticide (now banned from production and use in many countries) in the chlorinated hydrocarbon group.
FTU	Formazin Turbidity Units: A measure of turbidity.
Eh	A measure of the potential to transfer electrons from one atom, ion or molecule to another in an oxidation-reduction reaction (redox potential).
IJC	International Joint Commission: A binational organization established in 1909 by the Boundary Waters Treaty. Through the IJC, Canada and the United States co-operatively resolve problems along their common border, including water and air pollution, lake levels, power generation and other issues of mutual concern.
LC50	The concentration of a toxicant or effluent which is lethal to 50% of the test organisms over a specified time period.
LD50	That dose which is lethal to 50% of the test organisms over a specified time period.
LOI	Loss On Ignition: a measure (percentage) of organic fibre contained in sediment.
MISA	Municipal-Industrial Strategy for Abatement: The principal goal of this program is to clean up Ontario's waterways. It represents a new approach to controlling point source water pollution. MISA will control and reduce the amount of toxic contaminants in all industrial and municipal effluents discharged into Ontario's surface waters. The ultimate goal of MISA is the virtual elimination of toxic contaminants from all municipal and industrial discharges into the province's waterways.
MNR/OMNR	Ontario Ministry of Natural Resources
MOE/OMOE	Ontario Ministry of the Environment

OWDG	Open Water Disposal Guidelines (for dredged material)
PTS	Persistent Toxic Substance: Any toxic substance with a half-life in water of greater than eight weeks.
PSQG	Provincial Sediment Quality Guidelines
RAP	Remedial Action Plan: This is a plan to be developed with citizen involvement to restore and protect water quality of the Great Lakes. There are 42 Areas of Concern in the Great Lakes Basin which will develop a RAP.
U.S. EPA	United States Environmental Protection Agency
STP/WPCP	Sewage Treatment Plant/Water Pollution Control Plant
TEQ	Toxic Equivalency: the sum of dioxin and furan congeners expressed as being equivalent to 2,3,7,8-tetrachlorodibenzo-p-dioxin, the most toxic congener.
WWTP	Waste Water Treatment Plan

GLOSSARY

ALGA	(Algae) - Simple one-celled or many-celled micro-organisms capable of carrying on photosynthesis in aquatic ecosystems; a form of aquatic plant.
ANOXIA	The absence of oxygen which is necessary for sustaining most life. In aquatic ecosystems this term refers to the absence of dissolved oxygen.
BENTHIC/BENTHOS	Aquatic bottom living organisms.
BIOMASS	Total dry weight of all living organisms in a given area.
BIOMONITORING	The use of organisms to test the acute toxicity of substances in effluent discharges as well as the chronic toxicity of low-levels pollutants in the ambient aquatic environment.
CARCINOGEN	Cancer-causing chemicals, substances or radiation.
CHLORINATED ORGANICS	An organic compound which includes chemically bound chlorine. Thousands exist but only a small proportion of those formed in the kraft mill bleaching process (whenever chlorine is used) have been identified.
DISSOLVED OXYGEN	The amount of oxygen dissolved in water. See BIOCHEMICAL OXYGEN DEMAND.
DRAINAGE BASIN	A body of water and the land area drained by it.
DROGUE	A device used for measuring current speed and direction
ECOSYSTEM	The interacting complex of living organisms and their non-living environment; the biotic community and its abiotic environment.
EFFLUENT	Any liquid and associated material discharged from industrial or municipal sewage treatment plants directly or indirectly to any waters.
EPILIMNION	The warm, upper layer of water in a lake that occurs with summer stratification.
EROSION	The wearing away and transportation of soils, rocks and dissolved minerals from the land surface or along shorelines by rainfall, running water, or wave and current action.
EUTROPHICATION	The process of fertilization that causes high productivity and biomass in an aquatic ecosystem. Eutrophication can be a natural process or it can be a cultural process accelerated by an increase of nutrient loading to a lake by human activity.
EXOTIC SPECIES	Species that are not native to an area and have been intentionally introduced or have inadvertently infiltrated the system.
FOOD CHAIN	The process by which organisms in higher trophic levels gain energy by consuming organisms at lower trophic levels.

GREAT LAKES WATER QUALITY AGREEMENT	A joint agreement between Canada and the United States which commits the two countries to develop and implement a plan to restore and maintain the many desirable uses of the Great Lakes Basin.
GROUNDWATER	Water entrained and flowing below the surface which supplies water to wells and springs.
HYDROLOGIC CYCLE	The natural cycle of water on earth, including precipitation as rain and snow, runoff from land, storage in lakes, streams, and oceans, and evaporation and transpiration (from plants).
HYPOLIMNION	The cold, dense, lower layer of water in a lake that occurs with summer stratification.
LEACHATE	Materials suspended or dissolved in water and other liquids usually from waste sites that percolate through soils and rock layers.
LITTORAL	Productive shallow-water zone of lake in which light penetrates to the bottom, allowing vegetative growth.
NON-POINT SOURCE	Source of pollution in which pollutants are discharged over a widespread area or from a number of small inputs rather than from distinct, identifiable sources.
NUTRIENT	A chemical that is an essential raw material for the growth and development of organisms.
OLIGOTROPHIC	Oligotrophic waters support low levels of plant and animal life, as they are not high in nutrients. For this reason they usually contain high levels of dissolved oxygen. See TROPHIC STATUS
PATHOGEN	A disease-causing agent such as bacteria, viruses, and parasites.
PCBs	Polychlorinated biphenyls: A class of persistent organic chemicals that bioaccumulate.
pH	A measure of the acidIC or basic nature of water or some other medium. Values of pH below 7 represent acidic conditions and values above 7 are basic. A change of one unit, for example from 7 to 6, represents a ten-fold increase in acidity.
PHOTOSYNTHESIS	A process occurring in the cells of green plants and some microorganisms in which solar energy is transformed into stored chemical energy.
PHYTOPLANKTON	Minute, microscopic aquatic vegetative life.
PLUME	Due to temperature differences between effluent and the receiving waters, an effluent discharge will form a surface plume/bottom plume when it is warmer/cooler than the receiving waters.
POINT SOURCE	A source of pollution that is distinct and identifiable, such as an outfall pipe from an industrial plant.
PRIMARY TREATMENT	Stage of effluent treatment in which suspended solids are removed from effluent. Normally includes de-watering the recovered settled solids to facilitate landfilling or incineration.

RESUSPENSION	The remixing of sediment particles and pollutants (of sediment)back into the water by storms, currents, organisms and human activities such as dredging.
SECONDARY TREATMENT	Stage of waste treatment in which decompose organics constituents in effluent and reduce toxicity.
SEDIMENT	The fines or soils on the bottom of a body of water.
STRATIFICATION	The tendency for deep lakes to form distinct (or layering)layers of water as a result of vertical change in temperature and therefore in water density.
THERMOCLINE	A layer of water in deep lakes separating the cool hypolimnion (lower layer) from the warm epilimnion (surface layer).
TOXIC SUBSTANCE	As defined in the Great Lakes Agreement, any substance that adversely affects the health or well-being of any living organism.
TROPHIC STATUS	A measure of the biological productivity in a body of water. Aquatic ecosystems are characterized as oligotrophic (low productivity), mesotrophic (medium productivity) or eutrophic (high productivity).

APPENDIX 3.1 WATER QUALITY DATA FROM THE 1970, 1981 AND 1987/88 OMOE SURVEYS

APPENDIX 3.1 WATER QUALITY DATA FROM THE 1970 OMOE SURVEY (OMOE 1972)

(Station locations are shown in Figure 3.1)

SUMMARY OF WATER QUALITY DATA, 1970, - JACKFISH BAY

Station Location	Dissolved Oxygen % Saturation	BOD_5 mg/l	Solids Total mg/l	Solids Suspended mg/l	COD mg/l	Sulphates mg/l	Phenolic Substances µg/l	Colour Hazen Colour Units	pH	Turbidity (Jackson Units)
Blackbird Creek	-	175	1,100	105	695	15	550	1,375	6.2	> 150
Moberly Bay (Station)										
1	60	240	1,300	26	845	11	670	> 2,500	6.7	> 150
2	71	3.9	76	4	23	4	19	46	7.4	4
3	75	2.5	79	7	19	4	13	45	7.3	3
4	75	3.1	80	3.5	24	4.2	2	56	7.3	4.5
5	75	2.7	75	2.7	20	2.1	16	36	7.3	3.1
6	77	2.6	76	4	16	2.7	17	31	7.2	4.9
7	77	2.0	75	3.5	21	3	14	40	7.3	3
8	77	2.9	80	6.6	21	2.2	11	28	7.3	2.5
9	80	2.1	74	7	12.5	2	10	23	7.2	3
10	78	1.6	69	4.6	< 10	1	5	15	7.4	2
11	75	1.8	67	8	< 10	1.5	5	11	7.2	1.7
12	76	1.4	79	6	< 10	1	3.3	< 10	7.1	1.8
13	75	1.4	75	5	< 10	1	1	< 10	7.2	4.1
14	81	1.3	76	5	< 10	1	0	< 10	7.2	1.6
15	77	1.4	70	7	< 10	1	< 1	< 10	7.2	1.8
16	72	1.4	60	5	< 10	2	< 1	10	7.3	1.5
17	90	1.4	83	7.5	< 10	1	7.5	< 10	7.0	2.5
18	90	1.2	78	5	< 10	1	0	< 5	7.2	1.8
19	94	1.3	90	5	< 10	1	0	< 5	7.1	1.3
20	86	1.6	80	5	< 10	1	0	< 5	7.3	1.8
21	96	1.3	83	5	< 10	1	0	< 5	7.0	1.8
22	82	1.2	105	5	< 10	1	0	< 5	6.9	1.5

Station Location	Bacteriological Enumeration * Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	Phosphorus Total mg/l	Phosphorus Soluble mg/l	Nitrogen Free NH_3 mg/l	Nitrogen Total Kjel. mg/l	Nitrogen Nitrite mg/l	Nitrogen Nitrate mg/l
Blackbird Creek	-	-	-	0.185	0.110	0.38	1.2	0.07	0.03
Moberly Bay (Station)									
1	-	-	-	0.21	0.098	0.33	2.06	0.11	0.04
2	3,900	< 4	36	0.20	0.011	0.01	0.25	0.006	0.16
3	2,200	< 4	12	0.01	0.006	< 0.01	0.17	0.006	0.21
4	2,400	< 4	8	0.013	0.008	< 0.01	0.23	0.006	0.20
5	2,200	< 4	14	0.012	0.007	< 0.01	0.20	0.006	0.20
6	800	< 4	< 4	0.021	0.01	< 0.01	0.20	0.006	0.22
7	1,200	< 4	6	0.019	0.004	< 0.01	0.20	0.005	0.21
8	2,000	< 4	16	0.012	0.005	< 0.01	0.18	0.006	0.19
9	484	< 4	20	0.01	0.007	< 0.01	0.16	0.004	0.21
10	168	< 4	4	0.008	0.005	< 0.01	0.20	0.004	0.21
11	220	< 4	6	0.009	0.005	< 0.01	0.15	0.004	0.26
12	86	< 4	6	0.015	0.005	< 0.01	0.40	0.004	0.24
13	72	< 4	< 4	0.011	0.006	< 0.03	0.24	0.003	0.26
14	26	< 4	< 4	0.007	0.004	0.01	0.11	0.003	0.28
15	46	< 4	< 4	0.013	0.002	0.06	0.22	0.002	0.20
16	250	< 4	< 8	0.012	0.01	0.04	0.10	0.004	0.26
17	N.A.	< 4	< 4	-	0.003	0.02	0.24	0.003	0.25
18	12	< 4	< 4	0.012	0.005	0.02	0.15	0.003	0.27
19	16	6	12	0.007	0.003	0.01	0.18	0.003	0.28
20	40	< 4	< 4	0.013	0.005	< 0.01	0.14	0.003	0.28
21	14	< 4	< 4	0.013	0.004	< 0.01	0.11	0.002	0.28
22	10	< 4	< 4	0.015	0.005	0.01	0.14	0.003	0.29

* Means

APPENDIX 3.1 WATER QUALITY DATA FROM THE 1981 OMOE SURVEY (KIRBY 1986)

(Station locations are shown in Figure 3.2)

Summary of the Water Quality at Stations 701-726
in Jackfish Bay, 1981

	JUNE	SEPTEMBER
DOC (mg/L)		
median	4.1	1.6
range	1.2-88.5	0.5-57.5
COD (mg/L)		
median	20	-
range	<10-510	-
BOD (mg/L)		
median	1.8	0.6
range	0.1-75	0.1-50
COND (us/cm)		
median	155	106
range	100-1190	93-790
Suspended solids (mg/L)		
median	1	1
range	1-120	1-30
Colour (hazen units)		
median	29	10
range	1-931	4-855
Turbidity (FTU)		
median	0.6	0.30
range	0.15-3.4	0.15-9.5
Temperature (°C)		
median	10	13.5
range	6-14	12-14.5

- Insufficient Data

Summary of the Water Quality at Stations
Used in 1970 and 1981

	1970	1981
COD (mg/L)		
median	<10	34.2
range	<10-845	6.7-421.6
BOD (mg/L)		
median	1.6	3.9
range	1.2-240.6	0.1-71.9
Sulphate (mg/L)		
median	1.3	6.4
range	1-11	3.6-20.0
Colour (Hazen Units)		
median	10.5	72.2
range	2-2500	10.7-921.3
pH		
median	7.2	7.6
range	6.7-7.4	7.5-8.1
Reactive Phenolics (ug/L)		
median	10	33.5
range	<1-670	3-344.2

Concentrations (mg/L) of Metals Detected
at Station 701 in Jackfish Bay
- 1981 -

		Cadmium	Chromium	Copper	Nickel	Lead	Zinc
June 23	9:00 am	-	-	-	-	-	-
	11:00 am	0.003	0.015	0.010	0.005	0.042	0.050
	1:00 pm	0.002	0.020	0.009	0.007	0.039	0.060
	3:00 pm	0.002	0.011	0.010	0.004	0.048	0.050
June 24	9:00 am	0.002	0.009	0.040	-	-	0.050
	11:00 am	0.002	0.008	0.008	-	-	0.030
	1:00 pm	0.003	0.009	0.006	-	-	0.040
	3:00 pm	0.003	0.011	0.020	-	-	0.040
June 25	9:00 am	0.003	0.012	-	-	-	0.050
	11:00 am	0.003	0.011	-	-	-	0.050
	1:00 pm	0.002	0.007	-	-	-	0.050
	3:00 pm	0.002	0.009	-	-	-	0.040
Sept. 14	9:00 am	0.007	0.023	1.000	0.028	0.004	0.046
	11:00 am	0.002	0.017	1.200	0.012	0.002	0.042
	1:00 pm	0.002	0.013	2.000	0.017	0.001	0.090
	3:00 pm	0.002	0.011	0.008	0.015	0.001	0.038
Sept. 15	9:00 am	0.002	0.011	0.072	0.014	0.001	0.040
	11:00 am	0.002	0.013	0.047	0.014	0.001	0.031
	1:00 pm	0.002	0.011	0.008	0.017	0.001	0.028
	3:00 pm	0.002	0.011	0.008	0.015	0.001	0.029
Sept. 16	9:00 am	-	0.015	0.003	0.016	0.001	-
	11:00 am	-	0.009	-	0.016	0.001	-
	1:00 pm	-	-	-	-	-	-
	3:00 pm	-	-	-	-	-	-
Provincial Water Quality Objective		0.0002	0.100	0.005	0.025	0.005	0.030

- Not Sampled

Concentrations (ug/L) of Mercury in Jackfish Bay
- 1981 -

Station		June 23	June 24	June 25	Sept.14	Sept.15	Sept.16
701	9:00 am		0.14	-	<0.05	<0.05	0.08
	11:00 am	3.3	0.08	-	<0.05	<0.05	<0.05
	1:00 pm	1.1	<0.05	-	0.07	<0.05	<0.05
	3:00 pm	3.0	<0.05	-	0.05	<0.05	<0.05
702		3.0	0.05	0.11	<0.05	<0.05	<0.05
704		1.7	-	0.15	0.39	<0.05	<0.05
707		1.2	<0.05	0.16	<0.05	<0.05	<0.05
709		1.1	<0.05	<0.05	<0.05	<0.05	<0.05
710		1.2	<0.05	<0.05	<0.05	<0.05	<0.05
711		1.6	<0.05	<0.05	-	<0.05	-
712		-	-	-	-	<0.05	<0.05
713		0.73	<0.05	<0.05	-	-	-
714		0.92	0.05	<0.05	<0.05	<0.05	<0.05
719		1.7	-	0.10	<0.05	<0.05	<0.05

\- Not sampled.
Provincial Water Quality Objective = 0.2 ug/L

Concentrations (ug/L) of Phenolic Compounds Detected in Jackfish Bay - 1981

	2,3,4 TCP	2,4,6 TCP[2]	2,3.5,6 TTCP	PCP[1]	Phenol	Homovanillic Acid	Vanillin	Guaiacol	Aceto-vanillin
701 June 23	1.30	3.30	0.60	0.54	ND	-	-	-	-
24	ND	1.85	0.25	0.25	ND	263	100	235	-
25	0.23	0.70	0.13	-	ND	212	106	265	-
702 June 23	ND	2.00	0.30	0.25	ND	158	55	119	-
24	ND	1.60	0.25	ND	ND	79	36	77	-
704 June 23	0.08	0.52	0.08	0.11	ND	40	19	48	-
24	0.08	0.45	0.08	0.19	ND	ND	8	24	-
705 June 23	ND	0.24	ND	0.06	-	-	-	-	-
24	ND	ND	ND	ND	-	-	-	-	-
706 June 24	ND	0.45	0.07	0.05	-	-	-	-	-
707 June 23	ND	0.43	0.06	0.07	ND	19	8	18	-
710 June 23	ND	0.20	ND	ND	-	-	-	-	-
713 June 23	-	-	-	-	ND	ND	ND	ND	-
701 Sept. 14	ND	ND	ND	0.40	21.1	ND	ND	ND	5.2
15	ND	ND	ND	0.15	150.0	ND	18.4	139.2	84.0
16	ND	ND	ND	ND	42.2	ND	12.8	149.4	62.2
702 Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND	ND
704 Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND	ND
707 Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND	ND
709 Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND	ND
710 Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND	ND
712 Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND	ND
714 Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND	ND

TTCP - tetrachlorophenol
TCP - trichlorophenol
PCP - pentachlorophenol
ND = Not Detected
\- = Not Sampled
[1]Provincial Water Quality Objective for PCP = 0.5 ug/L
[2]Provincial Water Quality Objective for total TCP = 18 ug/L

Concentrations (mg/L) of Aromatic, Resin and Fatty Acids in Jackfish Bay, 1981

		Fatty Acids						Aromatic Acids	
		Lauric	Myristic	Palmitic	Stearic	Oleic	Arachidic	Benzoic	Phthalic
701	June 24	0.023	ND	0.08	0.036	0.140	0.105	0.064	0.034
	June 25	1.079	ND	0.079	0.041	0.131	0.205	0.098	0.0411
701	Sept. 14	ND	ND	0.02	ND	ND	ND	ND	ND
	Sept. 15	ND	0.05	0.04	ND	ND	ND	ND	ND
	Sept. 16	ND	ND	0.003	ND	ND	ND	ND	ND
702	Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND
704	Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND
709	Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND
710	Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND
712	Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND
714	Sept. 14	ND	ND	ND	ND	ND	ND	ND	ND

		Resin Acids					
		Pimaric	Sandaraco-pimaric	Levopimaric	Isopimaric	Neoabietic	Abietic
701	June 24	0.324	0.32	ND	0.54	0.5	1.36
	June 25	0.072	0.74	ND	1.21	1.2	2.27
701	Sept. 14	0.43	ND	0.06	0.15	ND	2.87
	Sept. 15	0.61	ND	0.49	0.38	0.09	2.62
	Sept. 16	0.48	ND	0.01	0.24	0.01	1.80
702	Sept. 14	ND	ND	0.43	0.04	ND	0.36
704	Sept. 14	ND	ND	ND	ND	ND	ND
709	Sept. 14	ND	ND	ND	ND	ND	ND
710	Sept. 14	ND	ND	ND	ND	ND	ND
712	Sept. 14	ND	ND	ND	ND	ND	ND
714	Sept. 14	ND	ND	ND	ND	ND	ND

ND - not detected.

APPENDIX 3.1 WATER QUALITY DATA FROM THE 1987/88 OMOE SURVEY (SHERMAN 1991)

(Station locations are shown in Figure 3.3)

Survey: 1 July 1987 open water stations (surface water)

Bay	Stn	RSP N	RSP Mean	Turbidity N	Turbidity Mean	BOD5 N	BOD5 Mean	DOC N	DOC Mean	Tannins N	Tannins Mean	Ammonium N	Ammonium Mean	Nitrates N	Nitrates Mean	Kjeldahl Nitrogen N	Kjeldahl Nitrogen Mean	Total Phosphorous N	Total Phosphorous Mean	Dissolved Reactive Phosphate N	Dissolved Reactive Phosphate Mean
---	---	-	----	-	----	-	----	-	----	-	----	-	----	-	----	-	----	-	----	-	----
MB	701	4	32.50	4	27.30	4	85.00	4	115.00	3	68.30	0	-	0	-	4	2.67	4	0.54	0	-
	803	3	28.30	3	26.30	3	93.70	2	134.00	2	67.50	0	-	0	-	3	2.67	3	0.57	0	-
	805	3	10.00	3	10.50	3	30.90	3	37.30	2	13.00	1	0.02	1	0.28	3	1.12	3	0.25	1	0.00
	702	3	8.67	3	8.63	3	28.80	2	73.50	2	8.50	2	0.02	2	0.13	3	0.96	3	0.19	2	0.02
	806	3	18.30	3	17.00	3	69.70	2	110.00	2	50.00	0	-	0	-	3	2.03	3	0.43	0	-
	807	2	7.00	2	3.05	2	8.60	2	21.00	2	12.00	2	0.02	2	0.08	2	0.58	2	0.10	2	0.01
	808	3	7.00	3	6.37	3	16.10	3	32.80	2	12.50	2	0.02	2	0.13	3	0.88	3	0.17	2	0.04
	809	3	6.67	3	4.20	3	6.80	3	19.80	3	7.00	3	0.02	3	0.09	3	0.63	3	0.09	3	0.01
	810	3	3.67	3	3.17	3	4.13	3	13.20	2	7.00	3	0.03	3	0.09	3	0.52	3	0.07	3	0.01
	811	3	3.67	3	2.57	3	3.17	2	10.00	2	5.50	3	0.02	3	0.11	3	0.42	3	0.05	3	0.01
	812	4	2.25	4	2.15	4	4.03	4	11.40	3	2.00	4	0.02	4	0.18	4	0.38	4	0.05	4	0.01
	813	3	3.67	3	3.13	3	4.13	3	14.60	2	8.50	3	0.03	3	0.09	3	0.50	3	0.06	3	0.01
	814	3	2.33	3	2.30	3	2.83	3	10.20	2	7.00	3	0.03	3	0.11	3	0.46	3	0.04	3	0.01
	815	3	3.33	3	2.52	3	3.33	3	10.20	1	2.00	3	0.02	3	0.11	3	0.42	3	0.05	3	0.01
	703	5	2.60	5	2.02	5	2.64	3	8.30	3	4.33	5	0.03	5	0.16	5	0.39	5	0.04	5	0.01
	704	6	2.83	6	2.15	6	2.88	3	9.53	4	4.25	6	0.02	6	0.18	6	0.34	6	0.03	6	0.00
	705	3	1.33	3	1.95	3	3.97	3	10.60	2	1.50	3	0.02	3	0.18	3	0.36	3	0.04	3	0.01
	816	3	3.00	3	2.33	3	3.00	2	7.50	1	5.00	3	0.04	3	0.11	3	0.46	3	0.05	3	0.01
	817	3	2.33	3	1.62	3	2.27	1	11.30	0	-	3	0.02	3	0.15	3	0.37	3	0.04	3	0.01
	818	3	1.67	3	1.10	3	1.60	1	2.80	1	1.00	3	0.03	3	0.21	3	0.28	3	0.02	3	0.00
	819	3	1.33	3	0.95	3	1.37	0	-	0	-	3	0.02	3	0.23	3	0.23	3	0.02	3	0.00
	706	3	2.67	3	1.77	3	2.33	3	8.83	3	7.00	3	0.03	3	0.15	3	0.40	3	0.04	3	0.01
	707	4	2.25	4	1.67	4	1.77	2	6.90	3	3.00	4	0.01	4	0.20	4	0.32	4	0.03	4	0.01
	708	3	1.00	3	0.83	3	1.07	3	3.77	2	1.50	3	0.02	3	0.25	3	0.22	3	0.02	3	0.00

Bay	Stn	RSP N	RSP Mean	Turbidity N	Turbidity Mean	BOD5 N	BOD5 Mean	DOC N	DOC Mean	Tannins N	Tannins Mean	Ammonium N	Ammonium Mean	Nitrates N	Nitrates Mean	Kjeldahl Nitrogen N	Kjeldahl Nitrogen Mean	Total Phosphorous N	Total Phosphorous Mean	Dissolved Reactive Phosphate N	Dissolved Reactive Phosphate Mean
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JB	709	3	2.33	3	0.98	3	1.67	3	7.33	2	7.00	3	0.04	3	0.17	3	0.33	3	0.03	3	0.00
	710	3	1.67	3	1.33	3	1.17	0	-	0	-	3	0.02	3	0.24	3	0.24	3	0.02	3	0.00
	711	3	1.00	3	0.48	3	0.63	0	-	0	-	3	0.01	3	0.28	3	0.18	3	0.01	3	0.00
	732	3	2.33	3	1.38	3	1.83	3	6.97	2	6.00	3	0.04	3	0.19	3	0.32	3	0.03	3	0.00
	714	3	1.00	3	1.40	3	0.77	0	-	0	-	3	0.02	3	0.26	3	0.22	3	0.01	3	0.00
	733	3	1.00	3	0.38	3	0.80	0	-	0	-	3	0.01	3	0.30	3	0.16	3	0.00	3	0.00
	715	3	1.67	3	1.13	3	1.50	2	2.30	1	1.00	3	0.04	3	0.21	3	0.29	3	0.02	3	0.00
	716	6	1.00	6	0.54	6	0.68	0	-	1	0.00	6	0.01	6	0.28	6	0.18	6	0.01	6	0.00
	735	3	1.00	3	0.43	3	0.60	0	-	0	-	3	0.01	3	0.29	3	0.16	3	0.00	3	0.00
	718	3	2.00	3	1.08	3	1.43	0	-	0	-	3	0.03	3	0.22	3	0.27	3	0.02	3	0.00
	719	3	1.00	3	0.45	3	0.67	0	-	0	-	3	0.01	3	0.29	3	0.17	3	0.01	3	0.00
	720	2	1.50	2	0.92	2	0.95	0	-	0	-	2	0.03	2	0.23	2	0.25	2	0.02	2	0.00
	721	3	1.00	3	0.25	3	0.37	0	-	0	-	3	0.01	3	0.30	3	0.14	3	0.00	3	0.00
	737	3	1.00	3	0.40	3	0.43	0	-	0	-	3	0.01	3	0.28	3	0.15	3	0.01	3	0.00
	723	2	1.00	2	0.28	2	0.55	0	-	0	-	2	0.01	2	0.30	2	0.14	2	0.00	2	0.00
	728	3	1.00	3	0.32	3	0.53	0	-	0	-	3	0.01	3	0.29	3	0.14	3	0.00	3	0.00
TB	712	3	1.00	3	0.35	3	0.53	0	-	0	-	3	0.01	3	0.29	3	0.17	3	0.00	3	0.00
	713	5	1.00	5	1.06	5	0.40	3	1.47	3	0.33	5	0.01	5	0.30	5	0.16	5	0.00	5	0.00
	832	3	1.00	3	0.35	3	0.47	3	1.57	2	0.50	3	0.01	3	0.29	3	0.16	3	0.00	3	0.00
	833	3	1.00	3	0.35	3	0.57	2	1.55	1	1.00	3	0.01	3	0.30	3	0.15	3	0.00	3	0.00

* all units mg/L except Turbidity (ftu)

MB - Moberly Bay JB - Jackfish Bay proper TB - Tunnel Bay

Survey: 1 July 1987 open water stations (surface water)

Bay	Stn	Calcium N	Calcium Mean	Magnesium N	Magnesium Mean	Sodium N	Sodium Mean	Potassium N	Potassium Mean	Alkalinity N	Alkalinity Mean	Sulphate N	Sulphate Mean	Chloride N	Chloride Mean	Conductivity N	Conductivity Mean	pH N	pH Mean
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MB	701	4	46.70	4	5.72	4	228.00	4	7.35	4	44.70	4	52.10	4	341.00	4	1405.00	4	6.35
	803	3	46.30	3	5.63	3	193.00	3	7.27	3	37.30	3	50.80	3	362.00	3	1450.00	3	6.10
	805	3	26.00	3	4.03	3	98.70	3	3.57	3	39.00	3	24.00	3	155.00	3	689.00	3	6.80
	702	3	26.70	3	3.87	3	92.00	3	3.17	3	39.70	3	22.70	3	137.00	3	626.00	3	6.90
	806	3	37.70	3	4.83	3	167.00	3	5.73	3	37.00	3	37.20	3	272.00	3	1120.0	3	6.40
	807	2	19.50	2	3.35	2	46.50	2	1.90	2	45.00	2	13.70	2	70.50	2	355.00	2	7.05
	808	3	21.00	3	3.50	3	57.30	3	2.31	3	41.00	3	16.10	3	89.30	3	451.00	3	7.03
	809	3	19.00	3	3.30	3	43.70	3	1.87	3	43.00	3	13.30	3	67.30	3	355.00	3	7.10
	810	3	16.70	3	3.10	3	28.30	3	1.33	3	43.00	3	9.10	3	43.00	3	259.00	3	7.17
	811	3	16.70	3	3.10	3	24.30	3	1.19	3	44.70	3	8.54	3	35.30	3	233.00	3	7.30
	812	4	16.00	4	3.08	4	23.80	4	1.17	4	43.20	4	8.37	4	35.00	4	230.00	4	7.33
	813	3	17.30	3	3.17	3	30.70	3	1.43	3	43.30	3	9.72	3	45.00	3	272.00	3	7.13
	814	3	16.00	3	3.03	3	21.70	3	1.11	3	43.70	3	7.46	3	31.00	3	215.00	3	7.30
	815	3	16.30	3	3.10	3	24.70	3	1.26	3	44.70	3	8.76	3	35.00	3	234.00	3	7.33
	703	5	15.80	5	3.00	5	18.60	5	1.02	5	43.40	5	7.35	5	28.60	5	206.00	5	7.32
	704	6	16.00	6	3.05	6	20.70	6	1.10	6	44.20	6	7.85	6	31.00	6	215.00	6	7.40
	705	3	16.70	3	3.07	3	23.10	3	1.15	3	42.70	3	8.17	3	35.10	3	228.00	3	7.43
	816	3	16.00	3	3.00	3	22.70	3	1.16	3	43.70	3	8.20	3	32.00	3	220.00	3	7.30
	817	3	15.70	3	3.00	3	16.70	3	1.00	3	44.30	3	6.92	3	23.70	3	193.00	3	7.43
	818	3	14.70	3	2.90	3	11.40	3	0.80	3	43.70	3	5.59	3	16.40	3	157.00	3	7.57
	819	3	14.30	3	2.90	3	9.67	3	0.72	3	43.70	3	5.12	3	13.70	3	147.00	3	7.60
	706	3	15.70	3	3.00	3	18.80	3	1.04	3	43.30	3	7.69	3	27.70	3	201.00	3	7.40
	707	4	14.80	4	2.95	4	13.20	4	0.84	4	43.70	4	6.13	4	18.50	4	174.00	4	7.45
	708	3	14.30	3	2.87	3	7.57	3	0.67	3	43.30	3	4.83	3	11.10	3	136.00	3	7.67

Bay	Stn	Calcium N	Calcium Mean	Magnesium N	Magnesium Mean	Sodium N	Sodium Mean	Potassium N	Potassium Mean	Alkalinity N	Alkalinity Mean	Sulphate N	Sulphate Mean	Chloride N	Chloride Mean	Conductivity N	Conductivity Mean	pH N	pH Mean
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JB	709	3	15.00	3	2.97	3	16.70	3	0.98	3	44.00	3	6.93	3	23.00	3	181.00	3	7.50
	710	3	14.30	3	2.90	3	8.80	3	0.72	3	43.70	3	4.95	3	11.40	3	139.00	3	7.67
	711	3	13.30	3	2.83	3	3.33	3	0.52	3	43.70	3	3.79	3	4.93	3	113.00	3	7.77
	732	3	15.00	3	2.97	3	14.60	3	0.97	3	44.00	3	6.72	3	21.00	3	174.00	3	7.50
	714	3	13.70	3	2.83	3	6.40	3	0.63	3	43.70	3	4.40	3	8.67	3	128.00	3	7.67
	733	3	13.30	3	2.83	3	2.77	3	0.53	3	43.70	3	3.54	3	3.50	3	107.00	3	7.87
	715	3	14.30	3	2.90	3	12.20	3	0.87	3	44.00	3	5.98	3	17.10	3	157.00	3	7.57
	716	6	13.70	6	2.85	6	4.28	6	0.56	6	43.50	6	3.99	6	5.75	6	116.00	6	7.75
	735	3	13.70	3	2.83	3	2.97	3	0.56	3	43.30	3	3.49	3	3.50	3	107.00	3	7.80
	718	3	14.70	3	2.90	3	11.30	3	0.83	3	43.70	3	5.66	3	15.40	3	152.00	3	7.57
	719	3	13.70	3	2.83	3	3.43	3	0.55	3	43.30	3	3.70	3	4.43	3	110.00	3	7.80
	720	2	14.50	2	2.90	2	8.55	2	0.73	2	44.00	2	5.03	2	12.00	2	138.00	2	7.70
	721	3	13.00	3	2.80	3	1.53	3	0.51	3	43.30	3	3.23	3	1.47	3	99.00	3	7.93
	737	3	13.70	3	2.80	3	3.07	3	0.53	3	43.30	3	3.56	3	3.40	3	108.00	3	7.83
	723	2	13.00	2	2.85	2	2.05	2	0.50	2	43.50	2	3.34	2	2.35	2	103.00	2	7.85
	728	3	13.30	3	2.83	3	2.40	3	0.51	3	43.30	3	3.48	3	2.83	3	104.00	3	7.87
TB	712	3	13.70	3	2.83	3	2.37	3	0.50	3	43.70	3	3.51	3	2.87	3	105.00	3	7.90
	713	5	13.00	5	2.80	5	1.98	5	0.49	5	43.40	5	3.42	5	2.04	5	101.00	5	6.46
	832	3	13.30	3	2.83	3	2.10	3	0.51	3	30.30	3	3.40	3	2.33	3	103.00	3	7.83
	833	3	13.30	3	2.80	3	2.00	3	0.53	3	43.30	3	3.41	3	2.23	3	102.00	3	7.83

* all units mg/L except conductivity(umhos/cm)
MB - Moberly Bay JB - Jackfish Bay proper TB - Tunnel Bay

Survey: 1 July 1987 open water (surface water)

Metal means*

Bay	Stn	Aluminum		Arsenic		Beryllium		Iron		Mercury		Cadmium		Chromium		Copper		Manganese		Nickel		Lead		Zinc	
		N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
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MB	701	4	<1.000	4	<0.001	4	<0.050	4	1.210	4	<0.010	4	<0.010	4	0.110	4	0.177	4	0.492	4	<0.100	4	<0.100	4	0.162
	803	3	<1.000	3	<0.001	3	<0.050	3	1.010	3	<0.010	3	<0.010	3	<0.100	3	<0.100	3	0.507	3	<0.100	3	<0.100	3	0.113
	805	3	0.437	3	<0.001	3	0.025	3	0.233	3	<0.010	3	<0.004	3	0.040	3	0.040	3	0.137	3	0.040	3	0.060	3	0.043
	702	2	0.565	3	<0.001	2	0.030	2	0.785	3	0.013	2	<0.005	2	0.055	2	0.055	2	0.245	2	0.055	2	0.055	2	0.055
	806	3	<1.000	3	<0.001	3	<0.050	3	0.770	3	0.013	3	<0.010	3	<0.100	3	<0.100	3	0.410	3	0.100	3	0.113	3	0.280
	807	2	0.105	2	<0.001	2	<0.010	2	0.170	2	<0.010	2	<0.001	2	0.015	2	<0.010	2	0.080	2	<0.010	2	<0.010	2	0.015
	808	3	0.708	3	<0.001	3	0.037	3	0.253	3	<0.010	3	<0.007	3	0.070	3	0.070	3	0.137	3	0.070	3	0.090	3	0.070
	809	3	0.400	3	<0.001	3	0.023	3	0.157	3	<0.010	3	<0.004	3	0.040	3	0.040	3	0.090	3	0.040	3	0.040	3	0.047
	810	3	0.107	3	<0.001	3	<0.010	3	0.117	3	<0.010	3	<0.001	3	<0.010	3	<0.010	3	0.060	3	<0.010	3	<0.010	3	0.013
	811	3	0.087	3	<0.001	3	0.007	3	0.107	3	<0.010	3	<0.001	3	0.009	3	0.007	3	0.044	3	0.007	3	0.008	3	0.009
	812	4	<0.100	4	<0.001	4	<0.010	4	0.133	4	<0.010	4	<0.001	4	0.013	4	<0.010	4	0.053	4	<0.010	4	<0.010	4	0.030
	813	3	<0.100	3	<0.001	3	<0.010	3	0.110	3	<0.010	3	<0.001	3	<0.010	3	0.023	3	0.053	3	<0.010	3	<0.010	3	0.013
	814	3	<0.100	3	<0.001	3	<0.010	3	0.110	3	<0.010	3	<0.001	3	<0.010	3	<0.010	3	0.037	3	<0.010	3	<0.010	3	0.030
	815	3	0.120	3	<0.001	3	<0.010	3	0.213	3	<0.010	3	<0.001	3	<0.010	3	<0.010	3	0.050	3	<0.010	3	0.013	3	0.013
	703	4	0.082	5	<0.001	4	<0.005	4	0.097	4	<0.010	4	<0.001	4	0.008	4	<0.006	4	0.034	4	0.006	4	0.009	4	<0.010
	704	5	0.064	6	<0.001	5	<0.005	5	0.067	6	<0.010	5	<0.001	5	0.006	5	<0.005	5	0.032	5	<0.005	5	0.008	5	0.009
	705	3	0.071	3	<0.001	3	0.007	3	0.120	3	<0.010	3	<0.001	3	0.007	3	0.007	3	0.038	3	0.007	3	0.008	3	0.011
	816	2	0.079	2	<0.001	2	<0.005	2	0.087	2	<0.010	2	<0.001	2	0.006	2	<0.005	2	0.036	2	0.006	2	0.008	2	0.022
	817	1	0.078	1	<0.001	1	<0.001	1	0.130	1	<0.010	1	<0.0003	1	<0.010	1	<0.001	1	0.054	1	<0.002	1	<0.003	1	0.009
	818	1	0.015	1	<0.001	1	<0.001	1	0.009	1	<0.010	1	<0.0003	1	<0.001	1	<0.001	1	0.007	1	<0.002	1	<0.003	1	0.003
	706	1	0.032	2	<0.001	2	<0.005	2	0.068	3	<0.010	2	<0.001	2	<0.005	2	<0.005	2	0.016	2	0.006	2	[illegible]	2	0.030
	707	2	0.043	4	<0.001	3	0.004	3	0.071	4	[illegible]	3	<0.001	3	0.006	3	0.004	3	0.028	3	<0.005	3	<0.005	3	0.007
	708	3	0.074	3	<0.001	3	0.007	3	0.080	3	<0.010	3	<0.001	3	0.007	3	0.007	3	[illegible]	3	0.007	3	0.011	3	0.008

Bay	Stn	Aluminum		Arsenic		Beryllium		Iron		Mercury		Cadmium		Chromium		Copper		Manganese		Nickel		Lead		Zinc	
		N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
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JB	709	2	0.053	3	<0.001	3	0.004	3	0.060	3	<0.010	3	<0.001	3	0.007	3	0.004	3	0.031	3	<0.005	3	0.006	3	0.037
	732	1	0.030	2	<0.001	2	<0.005	2	0.057	3	<0.010	2	<0.001	2	0.006	2	0.011	2	<0.010	2	0.006	2	0.112	2	0.135
	715	1	0.055	2	<0.001	2	<0.005	2	0.051	2	<0.010	2	<0.002	2	0.006	2	0.007	2	0.009	2	0.006	2	0.022	2	0.135
	716	3	<0.010	3	<0.001	3	<0.001	3	0.018	3	<0.015	3	<0.001	3	<0.001	3	<0.002	3	0.004	3	<0.002	3	<0.003	3	0.003
TB	713	3	0.039	5	<0.001	5	0.006	5	0.062	5	<0.010	5	<0.001	5	0.006	5	0.006	5	0.006	5	0.007	5	0.023	5	0.009
	832	2	0.014	3	<0.001	3	0.004	3	0.037	3	<0.010	3	<0.001	3	0.004	3	<0.005	3	<0.005	3	<0.005	3	0.022	3	0.004
	833	1	<0.010	2	<0.001	2	<0.005	2	0.058	2	<0.010	2	<0.001	2	<0.005	2	<0.005	2	0.007	2	0.006	2	0.007	2	<0.005

* all units mg/L

MB - Moberly Bay
JB - Jackfish Bay proper
TB - Tunnel Bay

Range of detection limits:

Aluminum	<.003 -- <.10	Mercury	<.01	Manganese	<.0005 -- <.01
Arsenic	<.001	Cadmium	<.0002 -- <.015	Nickel	<.001 -- <.10
Beryllium	<.0005 -- <.05	Chromium	<.005 -- <.10	Lead	<.005 -- <.15
Iron	<.001 -- <.10	Copper	<.0005 -- <.10	Zinc	<.0005 -- <.10

Survey: 2 August 1987 open water stations (surface water)

Bay	Stn	RSP N	RSP Mean	Turbidity N	Turbidity Mean	BOD5 N	BOD5 Mean	DOC N	DOC Mean	Tannins N	Tannins Mean	Ammonium N	Ammonium Mean	Nitrates N	Nitrates Mean	Kjeldahl Nitrogen N	Kjeldahl Nitrogen Mean	Total Phosphorous N	Total Phosphorous Mean	Dissolved Reactive Phosphate N	Dissolved Reactive Phosphate Mean
MB	701	6	21.70	6	25.30	6	53.50	6	96.90	6	64.20	2	0.01	4	0.07	6	2.17	6	0.37	2	0.01
	803	3	21.70	3	25.30	3	53.00	3	84.20	3	60.00	1	0.01	2	0.07	3	2.10	3	0.36	1	0.01
	805	3	5.67	3	6.70	3	6.57	3	22.20	3	26.00	3	0.03	3	0.03	3	0.73	3	0.09	3	0.01
	702	2	8.50	3	7.35	2	10.00	3	14.10	2	9.33	3	0.03	3	0.01	3	0.85	3	0.11	3	0.01
	806	2	25.00	2	10.30	2	27.80	3	47.30	2	37.50	1	0.03	2	0.06	2	1.25	2	0.18	0	-
	807	3	5.00	3	3.87	3	4.33	3	12.40	3	7.33	3	0.04	3	0.06	3	0.49	3	0.05	3	0.02
	808	3	4.33	3	6.47	3	6.33	3	18.60	3	10.70	3	0.04	3	0.02	3	0.70	3	0.08	3	0.01
	809	3	2.67	3	1.70	3	1.57	3	5.13	3	2.67	3	0.02	3	0.19	3	0.35	3	0.03	3	0.00
	810	3	4.00	3	4.03	3	4.73	3	11.30	3	8.00	3	0.05	3	0.05	3	0.59	3	0.06	3	0.01
	811	3	2.00	3	154.00	3	2.23	3	6.03	3	4.67	3	0.03	3	0.15	3	0.42	3	0.04	3	0.01
	812	3	12.30	3	4.47	3	3.93	3	11.70	3	6.33	3	0.04	3	0.07	3	0.53	3	0.05	3	0.01
	813	2	6.50	2	3.85	2	3.90	2	12.70	2	8.50	2	0.04	2	0.08	2	0.52	2	0.05	2	0.01
	814	3	4.33	3	3.20	3	3.97	3	11.20	3	7.00	3	0.05	3	0.07	3	0.56	3	0.06	3	0.01
	815	3	3.33	3	2.88	3	2.70	3	9.20	3	6.33	3	0.04	3	0.11	3	0.46	3	0.04	3	0.01
	703	3	2.33	3	2.53	3	2.13	3	7.07	3	3.67	3	0.03	3	0.14	3	0.38	3	0.04	3	0.01
	704	6	3.50	6	3.48	6	3.33	6	9.70	6	4.17	6	0.04	6	0.09	6	0.52	6	0.05	6	0.01
	705	3	1.00	3	0.55	3	0.23	3	1.87	3	1.67	3	0.01	3	0.27	3	0.18	3	0.01	3	0.00
	816	3	3.00	3	2.30	3	2.27	3	8.10	3	5.33	3	0.04	3	0.15	3	0.41	3	0.04	3	0.00
	817	3	2.67	3	1.63	3	2.47	0	-	0	-	3	0.04	3	0.13	3	0.44	3	0.04	3	0.01
	818	3	2.00	3	1.63	3	1.17	0	-	0	-	3	0.02	3	0.20	3	0.30	3	0.02	3	0.00
	819	3	1.33	3	0.53	3	0.30	0	-	0	-	3	0.01	3	0.26	3	0.17	3	0.01	3	0.00
	706	3	2.33	3	2.00	3	1.93	3	7.27	3	4.33	3	0.05	3	0.16	3	0.32	3	0.03	3	0.00
	707	5	2.40	5	2.58	5	1.78	5	6.20	5	3.80	5	0.02	5	0.16	5	0.36	5	0.03	4	0.00
	708	3	1.00	3	0.52	3	0.33	2	1.95	2	0.50	3	0.01	3	0.27	3	0.17	3	0.01	3	0.00

Bay	Stn	RSP N	RSP Mean	Turbidity N	Turbidity Mean	BOD5 N	BOD5 Mean	DOC N	DOC Mean	Tannins N	Tannins Mean	Ammonium N	Ammonium Mean	Nitrates N	Nitrates Mean	Kjeldahl Nitrogen N	Kjeldahl Nitrogen Mean	Total Phosphorous N	Total Phosphorous Mean	Dissolved Reactive Phosphate N	Dissolved Reactive Phosphate Mean
JB	709	3	1.67	3	1.70	3	1.30	3	5.13	3	2.67	3	0.04	3	0.19	3	0.32	3	0.02	3	0.00
	710	3	1.00	3	1.80	3	0.97	0	-	0	-	3	0.02	3	0.24	3	0.25	3	0.02	3	0.00
	711	3	1.00	3	0.52	3	0.40	0	-	0	-	3	0.01	3	0.26	3	0.17	3	0.01	3	0.00
	732	3	1.67	3	1.30	3	1.10	3	4.33	3	2.33	3	0.03	3	0.21	3	0.28	3	0.02	3	0.00
	714	5	1.00	5	0.82	5	0.80	0	-	0	-	5	0.02	5	0.25	5	0.22	5	0.01	5	0.00
	733	3	1.33	3	0.73	3	0.73	0	-	0	-	3	0.02	3	0.25	3	0.21	3	0.01	3	0.00
	715	3	1.67	3	1.18	3	1.20	1	4.90	1	2.00	3	0.02	3	0.22	3	0.28	3	0.02	3	0.00
	716	6	1.00	6	0.64	6	0.57	6	2.48	2	1.00	6	0.02	6	0.64	6	0.46	6	0.01	6	0.00
	735	3	1.00	3	0.47	3	0.33	0	-	0	-	3	0.01	3	0.27	3	0.17	3	0.01	3	0.00
	718	3	1.00	3	0.55	3	0.50	0	-	0	-	3	0.02	3	0.26	3	0.18	3	0.01	3	0.00
	719	3	1.00	3	0.42	3	0.40	0	-	0	-	3	0.01	3	0.27	3	0.17	3	0.01	3	0.00
	720	3	5.67	3	0.85	3	0.70	0	-	0	-	3	0.02	3	0.24	3	0.23	3	0.01	3	0.00
	721	3	1.00	3	0.30	3	0.33	0	-	0	-	3	0.01	3	0.28	3	0.14	3	0.00	3	0.00
	737	3	1.33	3	0.27	3	0.23	0	-	0	-	3	0.01	3	0.27	3	0.15	3	0.00	3	0.00
	723	2	1.00	2	0.25	2	0.25	0	-	0	-	2	0.01	2	0.28	2	0.15	2	0.00	2	0.00
	728	2	1.00	2	0.25	2	0.20	0	-	0	-	2	0.01	2	0.28	2	0.13	2	0.00	2	0.00
TB	712	3	1.00	3	0.45	3	0.23	0	-	0	-	3	0.01	3	0.27	3	0.16	3	0.01	3	0.00
	713	4	1.00	4	0.53	6	0.43	6	1.73	6	0.17	6	0.01	6	0.27	6	0.15	6	0.01	6	0.00
	832	3	3.33	3	0.57	3	0.20	3	1.90	3	0.33	3	0.01	3	0.26	3	0.17	3	0.01	3	0.00
	833	3	1.00	3	0.63	3	0.23	3	1.83	3	0.33	3	0.01	3	0.26	3	0.17	3	0.02	3	0.00

* all units mg/L except Turbidity(ftu)
MB - Moberly Bay JB - Jackfish Bay proper TB - Tunnel Bay

Survey: 2 open water stations (surface water)

Bay	Stn	Calcium N	Calcium Mean	Magnesium N	Magnesium Mean	Sodium N	Sodium Mean	Potassium N	Potassium Mean	Alkalinity N	Alkalinity Mean	Sulphate N	Sulphate Mean	Chloride N	Chloride Mean	Conductivity N	Conductivity Mean	pH N	pH Mean
MB	701	6	39.30	6	5.58	6	147.00	5	5.24	6	57.20	6	36.30	6	227.00	6	983.00	6	6.73
	803	3	39.00	3	5.63	3	108.00	3	5.27	3	57.00	3	35.80	3	222.00	3	983.00	3	6.77
	805	3	21.00	3	3.63	3	45.30	3	1.93	3	46.00	3	12.30	3	59.40	3	362.00	3	6.93
	702	2	21.00	2	3.80	2	47.50	3	1.90	2	45.00	2	12.00	2	72.40	2	362.00	2	7.00
	806	2	26.50	2	4.25	2	83.50	2	2.95	2	51.50	2	22.60	2	108.00	2	570.00	2	7.05
	807	3	16.70	3	3.23	3	24.70	3	1.23	3	45.00	3	8.84	3	34.70	3	244.00	3	7.17
	808	3	19.00	3	3.30	3	33.00	3	1.47	3	45.30	3	11.30	3	51.30	3	308.00	3	7.03
	809	3	15.00	3	2.97	3	10.90	3	0.77	3	43.30	3	5.24	3	15.40	3	154.00	3	7.57
	810	3	17.30	3	3.30	3	26.00	3	1.30	3	45.00	3	9.54	3	39.30	3	253.00	3	7.17
	811	3	15.00	3	2.97	3	14.60	3	0.89	3	43.30	3	324.00	3	21.90	3	166.00	3	7.47
	812	3	17.30	3	3.27	3	24.70	3	1.27	3	44.70	3	8.46	3	35.30	3	237.00	3	7.13
	813	2	17.00	2	3.20	2	23.50	2	1.10	2	42.50	2	7.29	2	36.10	2	228.00	2	7.15
	814	3	17.00	3	3.20	3	24.00	3	1.20	3	44.70	3	8.74	3	34.90	3	238.00	3	7.23
	815	3	15.70	3	3.13	3	15.60	3	0.93	3	43.00	3	6.69	3	24.00	3	193.00	3	7.40
	703	3	15.30	3	3.00	3	14.70	3	0.94	3	43.70	3	6.72	3	22.20	3	184.00	3	7.37
	704	6	16.50	6	3.13	6	22.30	6	1.13	6	44.70	6	8.10	6	28.70	6	223.00	6	7.23
	705	3	13.30	3	2.80	3	12.50	3	0.57	3	42.70	3	3.47	3	15.50	3	109.00	3	7.87
	816	3	15.70	3	3.00	3	14.40	3	0.91	3	43.30	3	6.95	3	22.30	3	177.00	3	7.40
	817	3	15.30	3	3.03	3	15.30	3	0.96	3	44.30	3	7.03	3	23.50	3	183.00	3	7.43
	818	3	14.00	3	2.93	3	7.90	3	0.74	3	43.00	3	4.91	3	13.00	3	143.00	3	7.67
	819	3	13.30	3	2.83	3	3.03	3	0.56	3	42.70	3	3.53	3	4.03	3	109.00	3	7.87
	706	3	15.30	3	3.00	3	13.50	3	0.92	3	44.00	3	6.61	3	20.30	3	173.00	3	7.43
	707	5	14.60	5	2.94	4	15.80	5	0.88	5	43.80	5	5.87	5	17.10	5	182.00	5	7.38
	708	3	13.30	2	2.80	3	2.87	3	0.55	3	42.70	3	3.54	3	3.77	3	108.00	3	7.83

Bay	Stn	Calcium N	Calcium Mean	Magnesium N	Magnesium Mean	Sodium N	Sodium Mean	Potassium N	Potassium Mean	Alkalinity N	Alkalinity Mean	Sulphate N	Sulphate Mean	Chloride N	Chloride Mean	Conductivity N	Conductivity Mean	pH N	pH Mean
JB	709	3	14.70	3	2.93	3	10.10	3	0.80	3	43.70	3	5.60	3	15.40	3	156.00	3	7.57
	710	3	14.30	3	2.83	3	6.93	3	0.70	3	43.70	3	4.55	3	9.53	3	132.00	3	7.70
	711	3	13.30	3	2.80	3	2.87	3	0.55	3	42.70	3	3.55	3	3.87	3	107.00	3	7.90
	732	3	14.00	3	2.90	3	8.20	3	0.73	3	43.30	3	5.03	3	12.10	3	142.00	3	7.60
	714	5	14.00	5	2.84	5	5.46	5	0.63	5	43.40	5	4.28	5	7.62	5	125.00	5	7.74
	733	3	13.70	3	2.87	3	5.20	3	0.63	3	43.70	3	4.29	3	7.03	3	123.00	3	7.80
	715	3	14.00	3	2.87	3	7.47	3	0.71	3	43.30	3	4.74	3	10.90	3	137.00	3	7.67
	716	5	13.60	5	2.76	6	4.15	5	0.61	6	43.00	5	4.26	5	6.06	6	113.00	6	7.73
	735	3	13.00	3	2.80	3	2.73	3	0.53	3	43.30	3	3.62	3	3.47	3	107.00	3	7.87
	718	3	13.70	3	2.80	3	3.77	3	0.60	3	43.00	3	3.85	3	5.03	3	113.00	3	7.80
	719	3	13.00	3	2.77	3	2.70	3	0.55	3	43.30	3	3.54	3	3.27	3	107.00	3	7.83
	720	3	13.70	3	2.87	3	5.13	3	0.62	3	42.70	3	4.08	3	7.37	3	122.00	3	7.73
	721	3	13.00	3	2.77	3	1.87	3	0.49	3	43.00	3	3.33	3	2.13	3	101.00	3	7.93
	737	3	13.00	3	2.73	3	1.77	3	0.50	3	43.00	3	3.32	3	2.03	3	101.00	3	7.93
	723	2	13.00	2	2.70	2	1.65	2	0.50	2	43.00	2	3.24	2	1.70	2	100.00	2	8.00
	728	2	13.00	2	2.70	2	1.55	2	0.47	2	43.00	2	3.25	2	1.65	2	100.00	2	8.00
TB	712	3	13.00	3	2.77	3	2.17	3	0.55	3	43.00	3	3.47	3	2.57	3	104.00	3	7.97
	713	4	13.00	4	2.75	4	2.17	4	0.52	4	43.00	4	3.43	4	2.67	4	104.00	4	7.93
	832	3	13.00	3	2.83	3	2.20	3	0.52	3	43.00	3	3.51	3	2.70	3	104.00	3	7.93
	833	3	13.00	3	2.77	3	2.20	3	0.52	3	43.00	3	3.52	3	2.80	3	105.00	3	7.90

* all units mg/L except conductivity(umhos/cm)

MB - Moberly Bay JB - Jackfish Bay proper TB - Tunnel Bay

Survey: 2 August 1987 open water (surface water)

Metal means*

Bay	Stn	Aluminum N	Aluminum Mean	Arsenic N	Arsenic Mean	Beryllium N	Beryllium Mean	Iron N	Iron Mean	Mercury N	Mercury Mean	Cadmium N	Cadmium Mean	Chromium N	Chromium Mean	Copper N	Copper Mean	Manganese N	Manganese Mean	Nickel N	Nickel Mean	Lead N	Lead Mean	Zinc N	Zinc Mean
MB	701	6	0.612	6	<0.001	6	0.025	6	1.140	6	0.012	6	0.011	6	0.040	6	0.023	6	0.307	6	0.023	6	0.063	6	0.057
	803	3	0.603	3	<0.001	3	0.025	3	0.853	3	<0.010	3	0.006	3	0.040	3	0.023	3	0.313	3	0.023	3	0.063	3	0.060
	805	3	0.147	3	<0.001	3	0.007	3	0.223	3	<0.010	3	<0.001	3	0.011	3	0.007	3	0.078	3	0.007	3	0.014	3	0.020
	702	3	0.140	3	<0.001	3	0.007	3	0.200	3	<0.010	3	<0.001	3	0.009	3	0.008	3	0.060	3	0.007	3	0.014	3	0.015
	806	3	0.243	3	<0.001	3	<0.010	3	0.343	3	<0.010	3	0.002	3	0.017	3	<0.010	3	0.127	3	<0.010	3	<0.020	3	0.013
	807	3	<0.100	3	<0.001	3	0.007	3	0.337	3	<0.010	3	<0.001	3	0.007	3	0.007	3	0.045	3	0.007	3	0.014	3	0.019
	808	3	0.123	3	<0.001	3	0.007	3	0.200	3	<0.010	3	<0.001	3	0.008	3	0.007	3	0.068	3	0.007	3	0.014	3	<0.010
	809	3	0.067	3	<0.001	3	<0.010	3	0.067	3	<0.010	3	0.002	3	<0.010	3	<0.010	3	0.023	3	<0.010	3	<0.020	3	<0.010
	810	3	0.120	3	<0.001	3	0.007	3	0.157	3	<0.010	3	<0.001	3	0.008	3	0.007	3	0.048	3	0.007	3	0.014	3	0.016
	811	3	0.053	3	<0.001	3	0.007	3	0.070	3	<0.010	3	<0.001	3	0.008	3	0.007	3	0.024	3	0.007	3	0.014	3	0.009
	812	3	0.098	3	<0.001	3	0.007	3	0.137	3	<0.010	3	<0.001	3	0.008	3	0.007	3	0.048	3	0.007	3	0.014	3	0.009
	813	2	0.120	2	<0.001	2	<0.005	2	0.185	2	<0.010	2	<0.001	2	0.008	2	0.006	2	0.053	2	<0.005	2	0.012	2	<0.010
	814	3	0.095	3	<0.001	3	0.007	3	0.133	3	<0.010	3	<0.001	3	0.008	3	0.007	3	0.047	3	0.007	3	0.014	3	0.009
	815	3	0.083	3	<0.001	3	0.007	3	<0.100	3	<0.010	3	<0.001	3	0.008	3	0.007	3	0.032	3	0.007	3	0.014	3	0.009
	703	3	0.067	3	<0.001	3	0.007	3	0.090	3	<0.010	3	<0.001	3	0.008	3	0.007	3	0.030	3	0.007	3	0.014	3	0.009
	704	6	0.081	6	<0.001	6	0.006	6	0.115	6	<0.010	6	<0.001	6	0.007	6	0.006	6	0.038	6	0.006	6	0.012	6	0.009
	705	3	0.017	3	<0.001	3	0.004	3	0.016	3	<0.010	3	<0.001	3	0.004	3	0.004	3	0.006	3	0.004	3	0.009	3	<0.005
	816	3	0.058	3	<0.001	3	<0.001	3	0.092	3	<0.010	3	<0.0003	3	0.003	3	<0.001	3	0.028	3	<0.001	3	<0.003	3	0.004
	706	3	0.052	3	<0.001	3	<0.001	3	0.078	3	<0.010	3	0.0004	3	0.004	3	<0.001	3	0.026	3	<0.001	3	<0.003	3	0.004
	707	5	0.064	5	<0.001	5	0.006	5	0.102	5	<0.010	5	<0.001	5	0.007	5	0.007	5	0.030	5	0.006	5	0.013	5	0.009
	708	2	0.011	2	<0.001	2	<0.001	2	0.019	2	<0.010	2	<0.0003	2	<0.001	2	<0.001	2	0.004	2	<0.001	2	<0.003	2	<0.002

Bay	Stn	Aluminum N	Aluminum Mean	Arsenic N	Arsenic Mean	Beryllium N	Beryllium Mean	Iron N	Iron Mean	Mercury N	Mercury Mean	Cadmium N	Cadmium Mean	Chromium N	Chromium Mean	Copper N	Copper Mean	Manganese N	Manganese Mean	Nickel N	Nickel Mean	Lead N	Lead Mean	Zinc N	Zinc Mean
JB	709	3	0.041	3	<0.001	3	<0.001	3	0.054	3	<0.010	3	<0.0003	3	0.002	3	<0.001	3	0.017	3	<0.001	3	<0.003	3	0.004
	732	3	0.034	3	<0.001	3	<0.001	3	0.074	3	<0.010	3	<0.001	3	0.002	3	<0.002	3	0.015	3	<0.001	3	<0.003	3	0.004
	715	1	0.027	1	<0.001	1	<0.001	1	0.038	1	<0.010	1	<0.0003	1	0.003	1	<0.001	1	0.015	1	<0.001	1	<0.003	1	<0.002
	716	6	0.016	6	<0.001	6	<0.001	6	0.028	6	<0.010	6	0.0004	6	<0.001	6	<0.002	6	0.006	6	<0.001	6	<0.005	6	0.003
TB	713	6	<0.010	6	<0.001	6	<0.001	6	0.011	6	<0.010	6	<0.0003	6	<0.001	6	<0.001	6	0.002	6	<0.001	6	0.004	6	<0.002
	832	3	0.014	3	<0.001	3	<0.001	3	0.045	3	<0.010	3	<0.0003	3	<0.001	3	<0.001	3	0.003	3	<0.001	3	<0.003	3	<0.002
	833	2	0.016	2	<0.001	2	<0.001	2	0.022	3	<0.010	2	<0.0003	2	<0.001	2	<0.001	2	0.003	2	0.003	2	<0.003	2	<0.002

* all units mg/L

MB - Moberly Bay
JB - Jackfish Bay proper
TB - Tunnel Bay

Range of detection limits:

Aluminum	<.003 -- <.10	Mercury	<.01	Manganese	<.0005 -- <.01
Arsenic	<.001	Cadmium	<.0002 -- <.015	Nickel	<.001 -- <.10
Beryllium	<.0005 -- <.05	Chromium	<.005 -- <.10	Lead	<.005 -- <.15
Iron	<.001 -- <.10	Copper	<.0005 -- <.10	Zinc	<.0005 -- <.10

Survey: 3 May 1988 open water (surface water)

		RSP		Turbidity		BOD5		DOC		Tannins		Ammonium		Nitrates		Kjeldahl Nitrogen		Total Phosphorous		Dissolved Reactive Phosphate	
Bay	Stn	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
---	---	-	----	-	----	-	----	-	----	-	----	-	----	-	----	-	----	-	----	-	----
MB	820	1	29.00	1	15.00	1	113.00	1	79.00	1	50.00	1	0.10	1	0.20	1	0.80	1	0.14	1	0.10
JB	843	2	1.00	2	0.50	2	0.40	2	1.10	2	0.00	2	0.06	2	0.32	2	0.16	2	0.01	2	0.00

* all units mg/L except Turbidity(ftu)

MB - Moberly Bay
JB - Jackfish Bay proper

Survey: 3 May 1988 open water (surface water)

		Calcium		Magnesium		Sodium		Potassium		Alkalinity		Sulphate		Chloride		Conductivity		pH	
Bay	Stn	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
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MB	820	1	69.00	1	4.90	1	163.00	1	5.55	1	100.00	1	38.40	1	250.00	1	1143.00	1	7.17
JB	843	2	13.00	2	2.80	2	1.30	2	0.46	2	43.00	2	3.05	2	1.25	2	98.50	2	7.65

* all units mg/L except conductivity(umhos/cm)

MB - Moberly Bay
JB - Jackfish Bay proper

Survey: 3 May 1988 open water (surface water)

Metal means*

Bay	Stn	Aluminum		Arsenic		Beryllium		Iron		Mercury		Cadmium		Chromium		Copper		Manganese		Nickel		Lead		Zinc	
		N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
MB	820	1	0.260	1	<0.001	1	<0.001	1	0.510	1	<0.010	1	<0.005	1	0.030	1	0.003	1	0.290	1	<0.005	1	<0.010	1	0.024

Bay	Stn	Aluminum		Arsenic		Beryllium		Iron		Mercury		Cadmium		Chromium		Copper		Manganese		Nickel		Lead		Zinc	
		N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
JB	843	2	<0.010	2	<0.001	2	<0.001	2	<0.020	2	<0.010	2	<0.0002	2	<0.001	2	<0.001	2	<0.001	2	<0.002	2	<0.005	2	<0.002

* all units mg/L

MB - Moberly Bay
JB - Jackfish Bay proper

Survey: 4 July 1988 open water stations (surface water)

Bay	Stn	RSP N	RSP Mean	Turbidity N	Turbidity Mean	BOD5 N	BOD5 Mean	DOC N	DOC Mean	Tannins N	Tannins Mean	Ammonium N	Ammonium Mean	Nitrates N	Nitrates Mean	Kjeldahl Nitrogen N	Kjeldahl Nitrogen Mean	Total Phosphorous N	Total Phosphorous Mean	Dissolved Reactive Phosphate N	Dissolved Reactive Phosphate Mean
MB	701	4	26.30	4	23.00	4	59.50	4	119.00	4	47.50	4	0.17	2	0.05	4	1.57	4	0.26	4	0.08
	803	2	32.50	2	25.00	0	-	2	117.00	2	50.00	2	0.15	1	0.05	2	3.35	2	0.55	2	0.05
	804	2	16.50	2	6.00	0	-	2	41.70	2	35.00	2	0.10	1	0.05	2	1.40	2	0.21	2	0.03
	805	2	4.50	2	3.00	0	-	2	25.40	2	11.50	2	0.13	2	0.08	2	0.68	2	0.07	2	0.01
	702	2	6.00	2	3.70	2	5.25	2	22.00	2	9.00	2	0.13	2	0.06	2	0.67	2	0.07	2	0.01
	806	2	14.00	2	8.50	0	-	2	57.00	2	18.50	2	0.10	1	0.05	2	1.08	2	0.15	2	0.02
	807	2	4.00	2	3.10	0	-	2	19.60	2	7.00	2	0.13	2	0.11	2	0.57	2	0.06	2	0.01
	808	2	4.50	2	2.60	0	-	2	19.60	2	7.00	2	0.14	2	0.06	2	0.55	2	0.05	2	0.01
	809	2	12.00	2	4.80	0	-	2	40.80	2	13.00	2	0.09	1	0.05	2	0.82	2	0.10	2	0.01
	810	2	3.50	2	2.65	0	-	2	11.30	2	9.50	2	0.12	2	0.14	2	0.50	2	0.05	2	0.01
	811	2	4.00	2	1.57	2	2.65	2	13.40	2	5.00	2	0.09	2	0.09	2	0.46	2	0.04	2	0.01
	812	2	2.50	2	2.25	0	-	2	15.90	2	5.00	2	0.12	2	0.15	2	0.43	2	0.04	2	0.01
	813	2	4.00	2	2.35	0	-	2	14.60	2	7.00	2	0.13	2	0.10	2	0.53	2	0.05	2	0.01
	814	2	5.00	2	3.65	0	-	2	19.20	2	7.50	2	0.14	2	0.05	2	0.59	2	0.06	2	0.01
	815	2	4.50	2	1.60	0	-	2	11.90	2	3.00	2	0.05	2	0.22	2	0.26	2	0.02	2	0.00
	703	2	2.00	2	1.65	2	1.85	2	9.30	2	4.00	2	0.07	2	0.16	2	0.34	2	0.03	2	0.01
	704	4	3.25	4	1.85	4	2.10	4	13.60	4	5.00	4	0.07	4	0.13	4	0.41	4	0.03	4	0.01
	705	2	1.50	2	1.25	0	-	2	4.05	2	1.50	2	0.05	2	0.20	2	0.29	2	0.02	2	0.01
	816	2	2.00	2	1.75	0	-	2	6.60	2	6.00	2	0.04	2	0.24	2	0.33	2	0.03	2	0.01
	817	2	2.50	2	1.65	0	-	0	-	0	-	2	0.07	2	0.16	2	0.34	2	0.03	2	0.01
	818	2	1.50	2	0.75	0	-	0	-	0	-	2	0.04	2	0.25	2	0.21	2	0.01	2	0.00
	819	2	1.50	2	0.82	0	-	0	-	0	-	2	0.03	2	0.26	2	0.21	2	0.01	2	0.00
	706	2	1.50	2	1.35	0	-	2	6.05	2	3.50	2	0.05	2	0.20	2	0.30	2	0.02	2	0.01
	707	2	1.50	2	1.65	2	1.30	2	5.35	2	2.50	2	0.04	2	0.22	2	0.30	2	0.02	2	0.00
	708	2	1.00	2	0.63	0	-	2	2.60	2	0.50	2	0.03	2	0.26	2	0.21	2	0.01	2	0.00

Bay	Stn	RSP N	RSP Mean	Turbidity N	Turbidity Mean	BOD5 N	BOD5 Mean	DOC N	DOC Mean	Tannins N	Tannins Mean	Ammonium N	Ammonium Mean	Nitrates N	Nitrates Mean	Kjeldahl Nitrogen N	Kjeldahl Nitrogen Mean	Total Phosphorous N	Total Phosphorous Mean	Dissolved Reactive Phosphate N	Dissolved Reactive Phosphate Mean
JB	709	2	1.00	2	1.17	0	-	2	6.65	2	2.50	2	0.06	2	0.19	2	0.30	2	0.02	2	0.00
	710	2	1.00	2	0.93	0	-	0	-	0	-	2	0.04	2	0.23	2	0.23	2	0.01	2	0.00
	711	2	1.00	2	0.63	0	-	0	-	0	-	2	0.02	2	0.28	2	0.16	2	0.00	2	0.00
	732	2	1.00	2	0.95	0	-	2	5.40	2	1.50	2	0.04	2	0.22	2	0.28	2	0.02	2	0.00
	714	2	1.00	2	0.63	0	-	0	-	0	-	2	0.02	2	0.27	2	0.17	2	0.01	2	0.00
	733	2	1.00	2	0.53	0	-	0	-	0	-	2	0.02	2	0.27	2	0.16	2	0.01	2	0.00
	715	2	1.00	2	0.73	2	1.15	2	3.40	2	0.50	2	0.03	2	0.26	2	0.22	2	0.01	2	0.00
	716	4	1.00	4	1.70	4	0.82	4	2.27	4	0.50	4	0.01	4	0.28	4	0.16	4	0.00	4	0.00
	735	2	1.00	2	0.53	0	-	0	-	0	-	2	0.02	2	0.28	2	0.19	2	0.01	2	0.00
	718	2	1.00	2	0.70	0	-	0	-	0	-	2	0.03	2	0.26	2	0.20	2	0.01	2	0.00
	719	2	1.00	2	0.47	0	-	0	-	0	-	2	0.02	2	0.28	2	0.15	2	0.00	2	0.00
	720	2	1.00	2	0.40	0	-	0	-	0	-	2	0.01	2	0.28	2	0.16	2	0.01	2	0.00
	721	2	1.00	2	0.45	0	-	0	-	0	-	2	0.01	2	0.28	2	0.14	2	0.00	2	0.00
	737	2	1.00	2	0.68	0	-	0	-	0	-	2	0.02	2	0.27	2	0.18	2	0.01	2	0.00
	723	2	1.00	2	0.35	0	-	0	-	0	-	2	0.01	2	0.29	2	0.16	2	0.00	2	0.00
	728	2	1.00	2	0.38	0	-	0	-	0	-	2	0.01	2	0.29	2	0.16	2	0.00	2	0.00
TB	712	2	1.00	2	0.60	0	-	0	-	0	-	2	0.02	2	0.27	2	0.19	2	0.01	2	0.00
	713	4	1.00	4	0.61	4	0.88	4	2.10	4	0.25	4	0.01	4	0.27	4	0.17	4	0.00	4	0.00
	832	2	1.50	2	0.68	0	-	2	2.35	2	0.50	2	0.03	2	0.27	2	0.20	2	0.01	2	0.00
	833	2	1.00	2	0.55	0	-	2	2.05	2	0.50	2	0.02	2	0.28	2	0.17	2	0.01	2	0.00

* all units mg/L except Turbidity(ftu) MB - Moberly Bay JB - Jackfish Bay TB - Tunnel Bay

Survey: 4 July 1988 open water stations (surface water)

Bay	Stn	Calcium N	Calcium Mean	Magnesium N	Magnesium Mean	Sodium N	Sodium Mean	Potassium N	Potassium Mean	Alkalinity N	Alkalinity Mean	Sulphate N	Sulphate Mean	Chloride N	Chloride Mean	Conductivity N	Conductivity Mean	pH N	pH Mean
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MB	701	4	50.20	4	5.35	4	240.00	4	9.45	4	193.00	4	74.80	4	286.00	4	1395.00	4	7.32
	803	2	47.50	2	5.15	2	245.00	2	9.40	2	194.00	2	76.10	2	278.00	2	1390.00	2	7.35
	804	2	32.50	2	4.15	2	140.00	2	6.55	2	124.00	2	31.20	2	166.00	2	590.00	2	7.05
	805	2	20.00	2	3.35	2	53.50	2	2.50	2	74.00	2	20.00	2	63.50	2	408.00	2	7.10
	702	2	22.00	2	3.30	2	56.50	2	2.50	2	75.00	2	19.50	2	67.50	2	412.00	2	7.20
	806	2	29.50	2	4.05	2	121.00	2	5.15	2	114.00	2	39.80	2	141.00	2	766.00	2	7.10
	807	2	18.00	2	3.10	2	39.00	2	2.05	2	64.50	2	13.90	2	46.00	2	316.00	2	7.20
	808	2	18.50	2	3.15	2	46.00	2	2.15	2	67.50	2	16.20	2	52.00	2	337.00	2	7.10
	809	2	24.50	2	3.70	2	84.50	2	3.80	2	92.00	2	29.10	2	102.00	2	573.00	2	7.10
	810	2	18.50	2	3.10	2	40.50	2	2.17	2	63.50	2	13.80	2	45.50	2	303.00	2	7.30
	811	2	17.50	2	3.10	2	33.00	2	1.70	2	61.50	2	11.90	2	37.00	2	274.00	2	7.25
	812	2	16.50	2	3.00	2	30.80	2	1.70	2	59.00	2	12.10	2	37.10	2	257.00	2	7.30
	813	2	18.00	2	3.20	2	41.00	2	1.90	2	66.00	2	13.20	2	41.50	2	323.00	2	7.10
	814	2	19.00	2	3.30	2	45.50	2	2.05	2	68.00	2	15.60	2	52.50	2	327.00	2	7.10
	815	2	14.50	2	3.10	2	14.70	2	1.00	2	56.50	2	7.18	2	13.40	2	423.00	2	7.30
	703	2	16.00	2	3.05	2	19.50	2	1.22	2	54.00	2	8.27	2	22.30	2	199.00	2	7.40
	704	4	17.00	4	3.05	4	24.00	4	1.45	4	58.00	4	10.30	4	28.00	4	234.00	4	7.25
	705	2	13.50	2	2.90	2	11.90	2	0.89	2	48.50	2	5.33	2	13.80	2	138.00	2	7.50
	816	2	14.00	2	2.95	2	11.40	2	0.83	2	50.50	2	6.24	2	14.10	2	160.00	2	7.50
	817	2	14.00	2	2.95	2	21.80	2	1.09	2	50.50	2	6.62	2	14.70	2	159.00	2	7.45
	818	2	13.50	2	2.90	2	7.30	2	0.71	2	48.00	2	4.95	2	8.55	2	135.00	2	7.55
	819	2	13.00	2	2.90	2	5.25	2	0.66	2	46.50	2	4.38	2	6.00	2	122.00	2	7.65
	706	2	14.50	2	2.95	2	14.50	2	1.00	2	51.50	2	6.90	2	17.00	2	170.00	2	7.45
	707	2	15.00	2	2.95	2	13.50	2	0.87	2	51.50	2	7.67	2	15.50	2	168.00	2	7.40
	708	2	13.00	2	2.90	2	5.45	2	0.65	2	47.00	2	4.33	2	5.80	2	121.00	2	7.65

Bay	Stn	Calcium N	Calcium Mean	Magnesium N	Magnesium Mean	Sodium N	Sodium Mean	Potassium N	Potassium Mean	Alkalinity N	Alkalinity Mean	Sulphate N	Sulphate Mean	Chloride N	Chloride Mean	Conductivity N	Conductivity Mean	pH N	pH Mean
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JB	709	2	15.50	2	3.00	2	16.00	2	1.06	2	52.50	2	7.74	2	18.00	2	177.00	2	7.35
	710	2	14.00	2	2.90	2	9.30	2	0.81	2	49.00	2	5.79	2	10.40	2	144.00	2	7.45
	711	2	13.50	2	2.80	2	2.90	2	0.56	2	45.50	2	3.66	2	3.35	2	107.00	2	7.75
	732	2	15.00	2	2.95	2	11.10	2	0.90	2	50.50	2	6.23	2	13.00	2	154.00	2	7.50
	714	2	14.00	2	2.85	2	3.20	2	0.59	2	46.00	2	3.96	2	3.80	2	109.00	2	7.65
	733	2	13.50	2	2.85	2	2.80	2	0.57	2	45.50	2	3.68	2	3.25	2	107.00	2	7.75
	715	2	14.00	2	2.85	2	6.35	2	0.71	2	48.50	2	5.12	2	8.85	2	134.00	2	7.55
	716	4	14.00	4	2.85	4	2.72	4	0.56	4	45.50	4	3.73	4	3.08	4	106.00	4	7.78
	735	2	14.00	2	2.85	2	2.60	2	0.55	2	45.50	2	3.54	2	2.85	2	105.00	2	7.75
	718	2	14.00	2	2.85	2	5.55	2	0.68	2	47.00	2	4.45	2	6.35	2	123.00	2	7.60
	719	2	14.00	2	2.85	2	1.70	2	0.52	2	45.00	2	3.18	2	1.80	2	99.50	2	7.80
	720	2	13.50	2	2.85	2	1.70	2	0.52	2	51.00	2	3.19	2	1.80	2	102.00	2	7.90
	721	2	14.00	2	2.85	2	1.70	2	0.51	2	45.00	2	3.18	2	1.80	2	100.00	2	7.80
	737	2	14.00	2	2.85	2	3.60	2	0.57	2	46.00	2	3.91	2	4.25	2	111.00	2	7.70
	723	2	14.00	2	2.85	2	1.40	2	0.50	2	45.00	2	3.10	2	1.40	2	98.50	2	7.80
	728	2	13.50	2	2.85	2	1.30	2	0.50	2	44.50	2	3.09	2	1.30	2	97.50	2	7.80
TB	712	2	12.50	2	2.90	2	3.80	2	0.60	2	46.50	2	3.94	2	4.35	2	113.00	2	7.70
	713	4	14.00	4	2.83	4	2.55	4	0.55	4	45.50	4	3.51	4	2.70	4	105.00	4	7.75
	832	2	12.50	2	2.90	2	3.80	2	0.60	2	46.50	2	3.91	2	4.45	2	113.00	2	7.70
	833	2	13.00	2	2.80	2	2.20	2	0.54	2	45.50	2	3.43	2	2.35	2	104.00	2	7.75

* all units mg/L except Conductivity(umhos/cm)

MB - Moberly Bay JB - Jackfish Bay proper TB - Tunnel Bay

Survey: 4 July 1988 open water (surface water)

Metal means*

Bay	Stn	Aluminum N	Aluminum Mean	Arsenic N	Arsenic Mean	Beryllium N	Beryllium Mean	Iron N	Iron Mean	Mercury N	Mercury Mean	Cadmium N	Cadmium Mean	Chromium N	Chromium Mean	Copper N	Copper Mean	Manganese N	Manganese Mean	Nickel N	Nickel Mean	Lead N	Lead Mean	Zinc N	Zinc Mean
MB	701	4	0.588	4	<0.001	4	<0.001	4	0.505	4	0.033	4	0.003	4	0.045	4	0.018	4	0.348	4	0.006	4	0.018	4	0.017
	803	2	0.445	2	<0.001	2	<0.001	2	0.490	2	0.025	2	0.003	2	0.035	2	<0.010	2	0.340	2	0.003	2	<0.010	2	0.039
	804	2	0.205	2	<0.001	2	<0.001	2	0.190	2	<0.020	2	<0.005	2	0.021	2	0.008	2	0.123	2	<0.005	2	<0.010	2	<0.005
	805	2	0.120	2	<0.001	2	<0.001	2	0.080	2	<0.010	2	<0.005	2	0.011	2	0.009	2	0.076	2	<0.005	2	<0.010	2	<0.005
	702	2	0.087	2	<0.001	2	<0.001	2	0.115	2	<0.010	2	<0.0002	2	0.012	2	0.003	2	0.073	2	<0.002	2	<0.005	2	0.008
	806	2	0.280	2	<0.001	2	<0.001	2	0.215	2	<0.010	2	<0.005	2	0.022	2	0.009	2	0.170	2	<0.005	2	<0.010	2	0.017
	807	2	0.040	2	<0.001	2	<0.001	2	0.075	2	<0.010	2	<0.005	2	0.007	2	<0.002	2	0.056	2	<0.005	2	<0.010	2	<0.005
	808	2	0.120	2	<0.001	2	<0.001	2	0.090	2	<0.010	2	<0.005	2	<0.010	2	0.007	2	0.068	2	<0.005	2	<0.010	2	<0.005
	809	2	0.200	2	<0.001	2	<0.001	2	0.140	2	0.015	2	<0.005	2	<0.010	2	0.009	2	0.115	2	<0.005	2	<0.010	2	<0.005
	810	2	0.055	2	<0.010	2	<0.001	2	0.080	2	<0.010	2	<0.005	2	0.008	2	<0.002	2	0.055	2	<0.005	2	<0.010	2	<0.005
	811	2	0.078	2	<0.001	2	<0.005	2	0.203	2	<0.010	2	0.004	2	0.011	2	0.007	2	0.044	2	0.013	2	0.007	2	0.009
	812	2	0.050	2	<0.001	2	<0.001	2	0.070	2	<0.010	2	<0.005	2	0.007	2	0.003	2	0.042	2	<0.005	2	<0.010	2	<0.005
	813	2	0.055	2	<0.001	2	<0.001	2	0.065	2	<0.010	2	<0.005	2	0.009	2	0.003	2	0.038	2	<0.005	2	<0.010	2	<0.005
	814	2	0.118	2	<0.001	2	<0.001	2	0.090	2	0.035	2	<0.005	2	0.011	2	0.006	2	0.062	2	<0.005	2	0.020	2	<0.005
	815	2	0.055	2	<0.001	2	<0.001	2	0.050	2	<0.010	2	<0.005	2	<0.005	2	0.003	2	0.016	2	0.007	2	<0.010	2	<0.005
	703	2	0.037	2	<0.001	2	<0.001	2	0.044	2	<0.010	2	<0.0002	2	<0.005	2	<0.002	2	0.027	2	<0.002	2	<0.005	2	<0.002
	704	4	0.047	4	<0.001	4	<0.001	4	0.059	4	<0.010	4	<0.0002	4	<0.005	4	<0.002	4	0.033	4	<0.002	4	<0.005	4	0.003
	705	2	0.040	2	<0.001	2	<0.001	2	<0.050	1	<0.010	2	<0.005	2	<0.005	2	0.004	2	0.011	2	<0.005	2	<0.010	2	<0.005
	816	2	0.035	2	<0.001	2	<0.001	2	0.050	2	<0.010	2	<0.005	2	<0.005	2	0.003	2	0.016	2	<0.005	2	<0.010	2	<0.005
	706	2	0.045	2	<0.001	2	<0.001	2	0.070	2	<0.010	2	<0.005	2	<0.005	2	0.003	2	0.022	2	<0.005	2	<0.010	2	<0.005
	707	2	0.034	2	<0.001	2	<0.001	2	0.030	2	<0.010	2	<0.0002	2	0.006	2	<0.002	2	0.016	2	<0.002	2	<0.005	2	0.001
	708	2	0.016	2	<0.001	2	<0.001	2	0.026	2	<0.010	2	<0.0002	2	0.002	2	<0.002	2	0.007	2	<0.002	2	<0.005	2	0.001

Bay	Stn	Aluminum N	Aluminum Mean	Arsenic N	Arsenic Mean	Beryllium N	Beryllium Mean	Iron N	Iron Mean	Mercury N	Mercury Mean	Cadmium N	Cadmium Mean	Chromium N	Chromium Mean	Copper N	Copper Mean	Manganese N	Manganese Mean	Nickel N	Nickel Mean	Lead N	Lead Mean	Zinc N	Zinc Mean
JB	709	2	0.035	2	<0.001	2	<0.001	2	0.050	2	<0.010	2	<0.005	2	<0.005	2	<0.002	2	0.020	2	<0.005	2	<0.010	2	<0.005
	732	2	0.026	2	<0.001	2	<0.001	2	0.031	2	<0.010	2	<0.0002	2	0.002	2	<0.002	2	0.014	2	<0.002	2	<0.005	2	<0.002
	715	2	<0.020	2	<0.001	2	<0.001	2	0.026	2	<0.010	2	<0.0002	2	0.002	2	<0.002	2	<0.010	2	<0.002	2	<0.005	2	0.001
	716	4	0.013	4	<0.001	4	<0.001	4	<0.020	4	<0.010	4	<0.0002	4	<0.001	4	<0.002	4	0.004	4	<0.002	4	<0.005	4	0.001
TB	713	4	0.015	4	<0.001	4	<0.001	4	<0.020	4	<0.010	4	<0.0002	4	<0.001	4	<0.002	4	0.003	4	<0.002	4	<0.005	4	0.001
	832	3	0.015	3	<0.001	3	<0.001	3	0.024	3	<0.010	2	<0.0002	2	0.002	2	<0.002	2	0.006	2	<0.002	2	<0.005	2	0.001
	833	2	0.013	2	<0.001	2	<0.001	2	<0.020	2	<0.010	2	<0.0002	2	<0.001	2	<0.002	2	0.003	2	<0.002	2	<0.005	2	0.001

* all units mg/L

MB - Moberly Bay
JB - Jackfish Bay proper
TB - Tunnel Bay

Range of detection limits:

Aluminum	<.003 -- <.10	Mercury	<.01	Manganese	<.0005 -- <.01
Arsenic	<.001	Cadmium	<.0002 -- <.015	Nickel	<.001 -- <.10
Beryllium	<.0005 -- <.05	Chromium	<.005 -- <.10	Lead	<.005 -- <.15
Iron	<.001 -- <.10	Copper	<.0005 -- <.10	Zinc	<.0005 -- <.10

APPENDIX 6.1 NEWSPAPER ADVERTISEMENTS AND BROCHURE

A:

You can get involved!

Public involvement is an important part of the RAP process! Programs to involve all those interested in or responsible for water quality in the four northern Lake Superior areas of concern are now underway. To find out more about what is planned for your community, and how you can get involved, call our toll free number, 1-800-465-6854, and leave a message for:

- Pat Inch, RAP Coordinator
  Peninsula Harbour
- Jim Murphy, RAP Coordinator
  Jackfish Bay
- Jake Vander Wal, RAP Coordinator
  Thunder Bay / Nipigon Bay

Environment Ontario
P.O. Box 5000, 435 James Street South
Thunder Bay, Ontario P7C 5G6

Remedial Action Plan
Plan d'Assainissement

Canada Ontario

Making a Great Lake Superior

RAP

NORTH SHORE
OF LAKE SUPERIOR
REMEDIAL ACTION PLANS

Q:

Are you concerned about water quality in Lake Superior?

So are the Federal and Provincial governments.

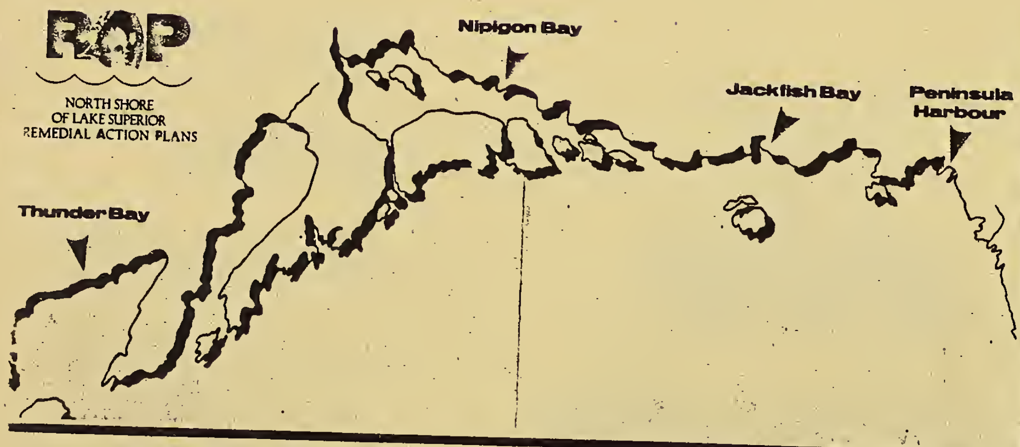
The International Joint Commission (IJC) has identified 42 polluted areas on the Great Lakes as areas of concern for which clean-up or remedial action plans (RAPs) must be prepared. Seventeen of these areas are located in Ontario, four on northern Lake Superior.

Under the Canada-Ontario Agreement Respecting Great Lakes Water Quality, Environment Ontario and Environment Canada are coordinating the development of the 17 Canadian RAPs. The Ministry of Natural Resources is playing an important role in the North Shore of Lake Superior Remedial Action Plans.

Each RAP will: define the boundaries of the affected area; identify the sources and causes of the pollution; identify the uses which are impaired; recommend remedial measures to restore desired uses; include an implementation timetable; identify the agencies responsible for implementing the RAP; and contain a process for measuring the degree to which restoration is achieved.

The contents of this brochure will familiariz[e] you with the reasons why there are four northern Lake Superior areas of concern: Thunder Bay, Jackfish Bay, Peninsula Harbour and Nipigon Bay.

NORTH SHORE
OF LAKE SUPERIOR
REMEDIAL ACTION PLANS



Northern Lake Superior Areas of Concern

Thunder Bay

Pollution problems in Thunder Bay identified around 1970 included gross pollution by raw sewage, bottom deposits of sludge and rotting woodwastes, floating sludgemats, foaming, and mercury and PCB contamination of sediments and fish.

Since that time, pollution abatement measures have been taken by the municipality and industry to improve water quality, but problems still exist.

Fish continue to die because of high loadings of organic wastes to the Kaministiquia River during low summer flow periods. The discharge of toxics, including persistent chlorinated organics to Thunder Bay from pulp and paper mills, have serious consequences to the Lake Superior ecosystem because many of these compounds do not break down easily, may cause cancer and genetic mutations, and may bioaccumulate in the food chain. A portion of the inner harbour has sediment seriously contaminated with dioxins, furans, pentachlorophenols, creosote and other toxic pollutants as a result of historical problems associated with the wood preserving industry. Fish are contaminated with mercury, PCBs and other contaminants. As well, bacterial contamination has resulted in periodic closures of Chippewa Beach.

Jackfish Bay

Water quality in Jackfish Bay, which has been monitored since 1969, is degraded as a result of industrial discharge to Blackbird Creek.

Although pollution control measures have resulted in less pollution entering the creek and, therefore, Jackfish Bay, serious pollution problems remain.

Toxic chemicals, including persistent chlorinated organics, are present. The water is discoloured. There are high levels of bacteria. Blackbird Creek and parts of Jackfish Bay are unable to support normal aquatic life owing to effluent toxicity and contamination of sediments. Fish are also contaminated with mercury.

Peninsula Harbour

Prior to 1984, water quality surveys indicated that the main impacts on this area of concern were: bacterial contamination; aesthetic impairment (odour and foam); high levels of mercury in fish and bottom sediments; and organic enrichment of the lake bottom.

Although measures have been undertaken to improve the water quality, pollution is still a problem.

Toxic chemicals, including persistent chlorinated organics from an industrial discharge, find their way to Lake Superior. Sediments remain contaminated with mercury as a result of historical discharges.

While fish in Peninsula Harbour are healthier now than in the past as a result of decreasing PCB and mercury concentrations, these contaminants still present a problem.

Nipigon Bay

Nipigon Bay receives municipal wastewater from Red Rock and Nipigon, as well as industrial wastewater from a pulp and paper mill.

Before 1974, pollution resulted in odours, tainting of fish flesh and changes to the aquatic community which included the replacement of clean water organisms by pollution tolerant forms.

Improvements to wastewater treatement since 1974 have contributed to improved water quality in the bay. However, water quality continues to be impaired.

Presently, there is an occasional taste problem in the drinking water. Furthermore, the industrial effluent which contains toxic chemicals including persistent chlorinated organics, remains concentrated in the surface water layer of Nipigon Bay.

JACKFISH BAY

RAP

NORTH SHORE
OF LAKE SUPERIOR
REMEDIAL ACTION PLAN

Open House

A cleanup or remedial action plan (RAP) is required for dealing with water pollution in Jackfish Bay.

You can get involved! Attend an open house to learn about the Jackfish Bay RAP and to meet and talk with the federal-provincial team coordinating the development of the RAP.

Thursday, December 1, 1988
2:00 p.m.-4:00 p.m. or 7:00 p.m.-9:00 p.m.
Terrace Bay Recreation Centre
Highway 17 and Selkirk Avenue
Terrace Bay, Ontario P0T 2W0

For further details please contact:
Jim Murphy
RAP Coordinator
Environment Ontario
3rd Floor, 435 James Street South
Thunder Bay, Ontario P7C 5G6
1-800-465-6854 (Toll Free)

Remedial Action Plan
Plan d'Assainissement

Canada Ontario

Jackfish Bay pollution is studied

By DARCEY CHERNYSH
North Shore Bureau

TERRACE BAY — Before they can plan their next move, the Jackfish Bay Public Advisory Committee must first determine how extensive pollution is in the bay, said the committee chairman.

First the group has to document if there is a pollution problem and, if so, how big of a problem it is. "So, we don't exactly know what the next step will be," said Jon Ferguson.

The committee has hired a consulting firm to test sediment content and depth at three locations along the Blackbird Creek system, including what is commonly referred to as Lake C which is closest to Lake Superior.

Samples were taken in early December and Ferguson said there is no word yet when the test results will be available. He also explained that the Ministry of the Environment will also be testing the samples.

Water quality in Jackfish Bay has been monitored for the past 20 years and, despite pollution control measures, pollution remains a problem. Industrial discharge in Blackbird Creek has left the water incapable of supporting normal aquatic life and parts of the bay itself cannot sustain normal aquatic life because of the toxic effluent and sediment contamination.

Even though the Kimberly-Clark paper mill has taken pollution control measures, Ferguson explained there is concern pollution could still be a problem further along the creek system.

"It could be worse," he said. "But there might be no difference (either)."

If a problem is seen the group will have to determine what clean-up action could be feasible. Removal of the contaminated sediment could be an option while another scenerio might see the sediment buried so deep such a move would be inappropriate.

The committee has to wait for the test results before even attempting to outline a plan of action, he added.

In the province, 17 polluted areas within the Great Lakes system have been identified as problem areas requiring investigation and clean-up. A remedial action plan is being developed to restore the water quality for each area with involvement from different levels of government and various interest groups.

Canada and the United States, through the International Joint Commission, are both examining the impact of pollution on the Great Lakes and establishing remedial action plans. The action plan will identify specific measures to control existing sources of pollution, abate environmental contamination already present and restore beneficial uses.

Other areas in the region with remedial action plan groups include Marathon's Peninsula Harbor, Nipigon Bay and Thunder Bay.

Study of Blackbird Creek system selects options to restore water quality

The Jackfish Bay Remedial Action Plan (RAP) Team, in consultation with the Public Advisory Committee (PAC), has commissioned a study of the Blackbird Creek system. This study will answer a number of questions which will assist the PAC and the RAP Team in selecting remedial options to restore the water quality and aquatic habitat of Jackfish Bay.

There were five specific questions put to the consultant. These are:

* Are the historic contaminants in Blackbird Creek and its associated lakes contributing to the overall toxic/contaminant load to Lake Superior? If so, where are the sources and how significant are they.

* If the pollutants, contained within the sediments of Blackbird Creek and its associated lakes, were to remain in place, for what period of time would they continue to contribute to the Lake Superior contaminant load?

* What remedial options are available to assist in the natural recovery of Blackbird Creek and its associated lakes and what are the costs of each option?

In the 1984 feasibility study of outfall alternatives, prepared for Kimberly-Clark of Canada Ltd., five options were proposed for effluent dispersion. The costs estimated for each option in this report were based upon 1984 dollars and construction methods. What costs would be essential with each option based upon current market conditions?

* Assuming that Kimberly-Clark of Canada Ltd. were to cease discharging effluent into Blackbird Creek system, how long would it take for the system to recover to background conditions (sediment and Water)?

The study has been completed and will be circulated for PAC review in early August. The PAC has also had the opportunity to review some introductory information regarding question four and a Preliminary Baseline Study of Vegetation and Rehabilitation Potential. This study outlines the use of wetlands as a cleaning system for Blackbird contaminants.

The PAC will be meeting to discuss this report on August 8, 7 p.m. at Birchwood Terrace in Terrace Bay. This meeting will become the first in a series of meetings where the PAC will review options and recommend what action will best achieve the water use goals for Jackfish Bay. PAC meetings are always open to the public.

APPENDIX 6.2 CHRONOLOGICAL DEVELOPMENT OF PUBLIC INVOLVEMENT

Date	Activity
December 1, 1988	Jackfish Bay Open Houses
May 9, 1989	Introductory PAC Meeting
May 18, 1989	PAC Meeting #2
June 22, 1989	Jackfish Bay Tour and PAC Meeting #3
July 13, 1989	Lake "A" Tour and PAC Meeting #4
August 10, 1989	PAC Meeting #5
September 14, 1989	PAC Meeting #6
October 19, 1989	Kimberly-Clark Mill Tour
November 9, 1989	PAC Meeting #7
November 21, 1989	Technical Terms Information Sessions
November 25, 1989	MISA Presentation for all four North Shore of Lake Superior PACs
December 7, 1989	PAC Meeting #8
January 4, 1990	PAC Meeting #9
February 1, 1990	PAC Meeting #10
February 22, 1990	PAC Meeting #11

March 22-24	Making a Great Lake Superior Conference
March 29, 1990	PAC Meeting #12
April 4, 1990	PAC Meeting #13
May 17, 1990	PAC Meeting #14
June 21, 1990	PAC Meeting #15
July 26, 1990	PAC Meeting #16
September 9, 1990	PAC Open House to present Water Use Goals to Public
September 27, 1990	PAC Meeting #17
November 22, 1990	PAC Meeting #18
December 13, 1990	PAC Meeting #19
February 18, 1991	PAC Meeting #20
March 23, 1991	Remedial Options Workshop for all four North Shore of Lake Superior PACs
April 11, 1991	PAC Meeting #21
May 23, 1991	PAC Meeting #22
August 8, 1991	PAC Meeting #23

APPENDIX 6.3 PAC TERMS OF REFERENCE

JACKFISH BAY REMEDIAL ACTION PLAN
PUBLIC ADVISORY COMMITTEE (PAC)
TERMS OF REFERENCE

THE REMEDIAL ACTION PLAN (RAP) PROCESS AND THE PAC

The RAP Process

The RAP Process will produce a plan that, when implemented, will restore and protect beneficial uses of Jackfish Bay.

The RAP will build on past and ongoing efforts and will be consistent with the requirements of the Great Lakes Water Quality Agreement of 1987 and the Canada-Ontario Agreement Respecting Great Lakes Water Quality.

A Canadian federal-provincial RAP Team has been created to coordinate the development of a Remedial Actin Plan.

The Public Advisory Committee (PAC)

The PAC will operate as an advisory body to the RAP Team, representing a variety of views on key aspects of the RAP preparation and implementation. The PAC will consider all views presented by the general public in formulating its consensus.

Objectives of the PAC

- to represent the range of community interests and concerns;
- to provide a focal point for the views and positions of the public in the development of the Jackfish Bay Remedial Action Plan;
- to assist the RAP team in implementing a public information program for the general public, in part by acting as a liaison between the PAC and its member organizations; and
- to provide a basis for generating community support for implementation of the final plan.

ROLES AND RESPONSIBILITIES

PAC: Group Responsibilities

The role of the PAC is to advise the RAP Team throughout the RAP development and implementation process. The PAC will:

- confirm and prioritize beneficial water uses to be restored;
- review results of research;
- provide input to and review descriptions of environmental conditions, sources and proposed remedial options, and the draft RAP document;
- contribute to and review the statements of goals and environmental conditions;

- identify parties responsible for implementation of remedial measures;
- review and comment on the scheduling of remedial measures;
- assist the RAP Team in designing a process to evaluate the effectiveness of remedial action measures;
- review and provide input on the overall public involvement program for both the planning and implementation phases; and
- review each stage of the Jackfish Bay RAP for consistency with goals and objectives of the PAC.

PAC: Individual Member Responsibilities

It is the responsibility of each individual appointed to the PAC to:

- prepare for and attend all PAC meetings;
- represent the views, interests and values of their respective group(s) (if they represent a group). This means communicating all information and viewpoints back to the group(s) to seek support and positions on issues discussed at PAC meetings and to convey the group's positions back to the PAC;and
- promote community awareness, understanding and support for implementation of the RAP.

In addition, attendance at open houses and meetings for the general public (2 to 3 meetings per year) by PAC representatives would be desirable.

MEMBERSHIP AND REPRESENTATION

General

It is the intent of the RAP Team to have a wide range of community representation on the PAC. Membership on the PAC shall attempt to include individuals representing community organizations, local government agencies and the general public having a direct effect on, or being directly affected by, the water quality of Jackfish Bay. The PAC may also include groups or individuals having an interest in the uses and management of local waters.

PAC Organization

Initially, the PAC shall meet and determine operating rules of procedure, including frequency of meetings, time, location, the need for additional members, etc., and shall review these rules of procedure with the RAP Team. The RAP Coordinator or alternate shall attend all PAC meetings.

Agenda and supporting reports shall be distributed in advance of any meeting in order to ensure that all members of the PAC are kept fully informed.

The PAC may appoint sub-committees to address specific issues. Members of the sub-committees need not be members of the PAC.

PAC meetings are open for anyone to attend as an observer. Adequate notice of all PAC meetings shall be provided to PAC members, interested parties and the public.

The PAC can meet as often as necessary during the day, evenings or on weekends, as determined by the membership.

Facilitator

Services of a facilitator to assist the PAC will be provided to the PAC by the RAP team.

Specific duties of the facilitator may include organizing meeting dates and locations, preparing agenda and minutes, circulation of reports, and attendance at PAC meetings.

Chairmanship

A Chairman shall preside over PAC meetings. The Chairman's objective shall be to discuss all issues fairly and manage the meeting so as to achieve a consensus on each issue for presentation to the RAP Team.

The criteria for selection of a Chairman must centre on the individual's ability to oversee and direct the workings of a diverse grouping of interests in meeting the PAC's objectives. Appointment of the Chairman shall be made by the PAC as a whole.

The PAC may determine whether an alternate to the Chairman should be designated and whether the Chair should be rotated.

APPENDIX 6.4 JACKFISH BAY WATER-USE GOALS

JACKFISH BAY PUBLIC ADVISORY COMMITTEE
WATER USE GOALS

SHORT-TERM WATER USE GOAL

Reduction of toxins, particularly chlorinated organic compounds, from point sources in order to meet or exceed Federal and Provincial guidelines.

LONG-TERM WATER USE GOALS

1. Safe Drinking Water

Jackfish Town cottagers should be able to drink the water from Jackfish Bay following standard treatment methods; and the water entering the Jackfish Bay area of Lake Superior from the Blackbird Creek system must be safe for consumption.

2. Fisheries

The fish habitat and spawning areas in Blackbird Creek and Jackfish Bay must return to a healthy hospitable state.

The fishery of Blackbird Creek and Jackfish Bay must be part of a balanced and healthy aquatic community.

All fish caught in Blackbird Creek and Jackfish Bay must be safe for consumption at any size or quantity and have contaminant levels that are less than, or at most, equal to background levels.

3. Recreational Uses

The water in Jackfish Bay must be clean and odourless for swimming, boating and scuba diving. Blackbird Creek and Jackfish Bay must be returned to natural conditions in order to support trapping and hunting. The aesthetic of Blackbird Creek and Jackfish Bay should be improved in order to encourage tourism and educational trips.

4. Wastewater Receiver

Blackbird Creek and Jackfish Bay can continue to be used for mill effluent discharge providing that it does not impair beneficial uses, inhibit indigenous biota or produce other adverse impacts on the ecosystem.

5. Delisting

Water quality conditions should be improved to the point that Jackfish Bay is no longer an area of concern as defined by the Great Lakes Water Quality Agreement.

Remedial Action Plan
Plan d'Assainissement

Canada Ontario

Canada-Ontario Agreement Respecting Great Lakes Water Quality
L'Accord Canada-Ontario relatif à la qualité de l'eau dans les Grand Lacs